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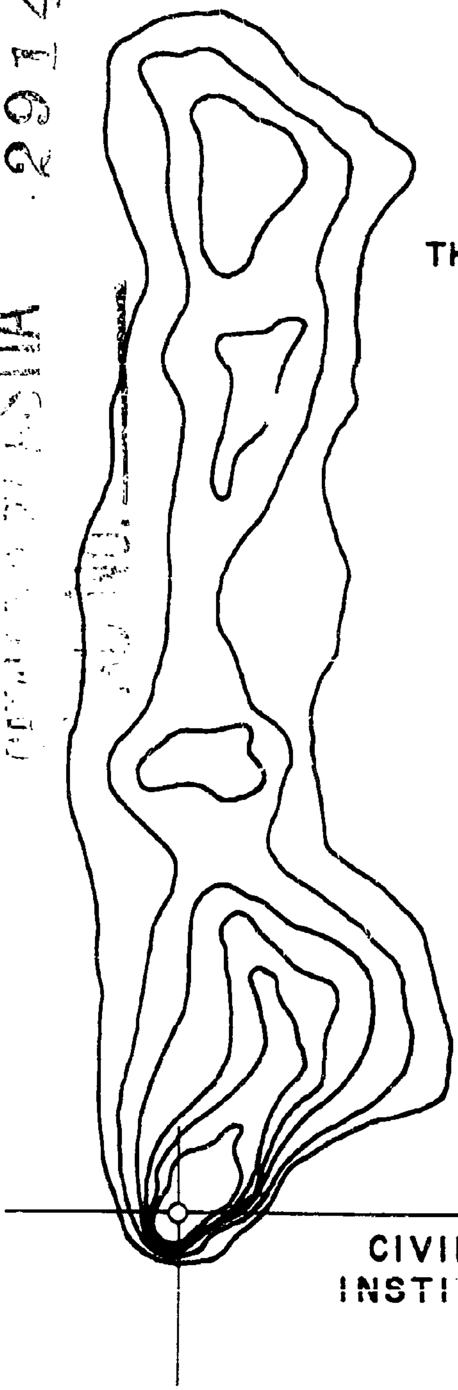
CDRP-182-106



THE APPLICATION OF THE EQUIVALENT RESIDUAL DOSE CONCEPT TO OPERATIONAL PLANNING TECHNIQUES

BY

Myron B Hawkins

October 10,1962

CIVIL DEFENSE RESEARCH PROJECT
INSTITUTE OF ENGINEERING RESEARCH
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ABSTRACT

The equivalent residual dose concept proposed by the National Committee on Radiation Protection permits a more reliable prediction of the medical effects of nuclear radiation exposure during emergency conditions. This study investigates the use of this dose concept during the complex operational situations in the postattack period of a nuclear war. Preliminary planning aids have been developed to permit prediction of the maximum equivalent residual dose encountered in operational regimens involving three phases of radiation protection. Other parameters that can be varied are stay-times in each phase, the permissible dose, and the fallout radiation intensity level. The basic computer program can incorporate a much wider variety of parameters including daily changes in equivalent protection factor, variation in first day radiation exposure, decay rate, etc.

The planning aids have been applied to a partial evaluation of standard fallout shelter specifications and the requirements for secondary shelter. The latter study indicates that the use of secondary shelters having a protection factor of about 10 and which could serve as temporary living and working areas would permit significant reductions in primary shelter stay-times.

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I. INTRODUCTION

The radiation exposure of persons in the fallout area is a critical problem in the postattack period of a nuclear war. An adequate fallout shelter program will provide radiation protection for the population, provided it stays in the shelter. However, since the over-all survival of the nation depends on the rapid recovery of vital production and distribution systems, the operation of utilities, public service functions and important industries in the fallout area must be continued during the attack or re-initiated soon afterward. The radiation protection available at many of these facilities will be such that uncontrolled operations will result in radiation casualties. Generally, these casualties can be prevented by alteration of the work schedule, the rotation of the personnel assignments, postponing the start of the operation, using available shelter, providing additional shelter or by introducing other countermeasures. Advance planning is necessary if such measures are to be taken efficiently. Vital to such planning is a means of computing the radiation exposure in a manner that permits a reliable prediction of the medical and biological consequences of the exposure. The equivalent residual dose concept recently proposed (ref.1) by the National Committee on Radiation Protection and Measurements provides this means. The equivalent residual dose* (ERD) is the accumulated dose corrected for the biological recovery that has occurred. The NCRP report relates various ERD levels to biological effects, thus providing the information needed for a planning technique.

A previous report (ref.2) of this project presented a technique for computing the accumulated dose history during various postattack operational situations. This study preceded the ERD concept and suffered because the

* At one time, the "equivalent residual dose" was called the "effective biological dose" (EBD). This expression is found in some of the earlier reports on the subject.

dose criteria used in it had no authoritative validity. However, the study detailed the important parameters of the postattack situation, making it possible to draw qualitative conclusions regarding the requirements for shelter and decontamination.

This study is an extension of the previous report in that a technique for determining the ERD for complex operational systems has been developed. The technique is presented in this report in a form that is more useful for preattack planning than it is for postattack planning. The information has been used to evaluate the importance of certain shelter requirements and the need for secondary shelter.

II. OBJECTIVES

The primary purpose of this study has been to develop methods of predicting radiation exposures in complex operational situations in such a manner that planning decisions can be made to control or limit such exposures. At present, the methods are presented in a form that is useful primarily for the preattack planning of postattack operations. However, the methods will provide bases for the development of simplified planning techniques for the postattack planning of postattack operations.

As secondary objectives of the study, investigations have been made of various generalized operational situations in order to determine in a preliminary manner:

a) the significance of existing shelter specifications relative to protection factor and stay-time,

b) the requirements and specifications for secondary shelter.

III. THE EQUIVALENT RESIDUAL DOSE CONCEPT

The justification for the use of the equivalent residual dose (ERD) concept to evaluate radiation exposure in the postattack period is given by the NCRP (ref.1). The primary reason for adoption of this approach is that it "permits a more reliable prediction of the biological and medical consequences of exposure to radiation than is possible on the basis of accumulated dose alone. By definition, ERD is the accumulated dose corrected for such recovery as has occurred at a specific time."

The assumptions used in the NCRP report* are:

1. Ten per cent of the injury attributed to dose is considered irreparable.
2. The body repairs the remaining 90 per cent at the rate of 2.5 per cent per day.
3. Recovery after a brief exposure (i.e., delivered over a period of a few seconds to 4 days) begins 4 days after the start of the exposure.
4. Recovery is continuous during protracted exposure.

The equation describing ERD at t days in the NCRP report is given as a function of a constant daily dose subsequent to the fourth day. Since the fallout radiation intensity decreases due to decay of the radioactive materials, the assumption of a constant daily dose is not practical for post-attack operational situations.

Although a means of computing the ERD manually had been developed by this project (ref.3) and considered for operational use (ref.4), it was felt to be too cumbersome and slow for the purposes of this investigation. As a consequence, a program (ref.5) for an IBM-704 computer was developed on the

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* See ref. 1, page 86.

basis of the following equations:

$$E_i/R_1 = d_i + d_i^*$$

where E_i = the ERD on the i^{th} day, roentgens

R_1 = the reference radiation intensity (i.e., r/hr at 1 hr)

where d_i (the recoverable dose on the i^{th} day), r

$$= 0.975\ d_{i-1} + 0.9\ \frac{r_i}{p_i}$$

d_i^* (the non-recoverable dose on the i^{th} day), r

$$= d_{i-1}^* + 0.1\ \frac{r_i}{p_i}$$

and r_i = the exposure rate (r/day) in an unprotected location, based on an R_1 of 1 r/hr

p_i = the effective protection factor achieved on the i^{th} day.

The program computes E_i/R_1 for each day, "remembering" the peak value encountered. The print-out gives the peak value, and the day it occurs. In addition, it gives the non-recoverable dose and the recoverable dose at the last day calculated. A typical print-out sheet is reproduced in Figure 1. The explanation of the symbols is as follows:

CODE: An arbitrary number assigned each computation.

LAST DAY CALC: The last day for which the ERD is calculated. (input data)

PERIOD 1; 1ST DAY, P.F.: This indicates the day the first period starts (always the first day) and the equivalent protection factor obtained during the first period. (input data)

PERIOD 2; 1ST DAY, P.F.: This gives the day the second period starts and the equivalent protection factor appropriate for the period. (input data)

EQUIVALENT RESIDUAL DOSE CALCULATIONS (ERD)

THREE STAGE PF1= 100, PF2=10, PF3= 4 INFLUENCE OF STAY-TIMES

CODE	LAST DAY CALC	PERIOD 1 1ST DAY	PERIOD 1 P.F.	PERIOD 2 1ST DAY	PERIOD 2 P.F.	PERIOD 3 1ST DAY	PERIOD 3 P.F.	PERIOD 4 1ST DAY	PERIOD 4 P.F.	MAX ERD/R	AT DAY	FINAL REC DOSE	FINAL UNREC DOSE
1334	365	1	100.	3	10.	4	4.			0.14041	20	0.00365	0.03131
1335	365	1	100.	3	10.	8	4.			0.11059	24	0.00365	0.02699
1336	365	1	100.	3	10.	11	4.			0.09962	27	0.00365	0.02541
1206	365	1	100.	3	10.	15	4.			0.08985	29	0.00365	0.02404
1207	365	1	100.	3	10.	31	4.			0.07366	16	0.00364	0.02129
1208	365	1	100.	3	10.	61	4.			0.07366	16	0.00364	0.01917
1209	365	1	100.	3	10.	91	4.			0.07366	16	0.00363	0.01808
1210	365	1	100.	3	10.	151	4.			0.07366	16	0.00361	0.01685
1211	365	1	100.	3	10.	211	4.			0.07366	16	0.00354	0.01611
1337	365	1	100.	5	10.	6	4.			0.10658	25	0.00365	0.02624
1338	365	1	100.	5	10.	8	4.			0.09611	27	0.00365	0.02463
1339	365	1	100.	5	10.	11	4.			0.08589	30	0.00365	0.02305
1212	365	1	100.	5	10.	15	4.			0.07686	33	0.00364	0.02167
1213	365	1	100.	5	10.	31	4.			0.05764	43	0.00364	0.01892
1214	365	1	100.	5	10.	61	4.			0.05644	20	0.00363	0.01681
1215	365	1	100.	5	10.	91	4.			0.05644	20	0.00363	0.01572
1216	365	1	100.	5	10.	151	4.			0.05644	20	0.00360	0.01448
1217	365	1	100.	5	10.	211	4.			0.05644	20	0.00354	0.01374
1340	365	1	100.	8	10.	9	4.			0.08236	31	0.00365	0.02236
1341	365	1	100.	8	10.	11	4.			0.07645	33	0.00364	0.02139
1218	365	1	100.	8	10.	15	4.			0.06804	37	0.00364	0.02001
1219	365	1	100.	8	10.	31	4.			0.05049	48	0.00364	0.01727
1220	365	1	100.	8	10.	61	4.			0.04482	24	0.00363	0.01515
1221	365	1	100.	8	10.	91	4.			0.04482	24	0.00363	0.01406

Figure 1
Typical "print-out" sheet

PERIOD 3 (and 4, etc.): Same as previous description. Almost any number of separate periods can be accommodated although four should be adequate to describe most operational situations.

MAX ERD/R: The maximum or peak equivalent residual dose encountered during the entire computation. It is expressed as a fraction of the 1-hour-intensity, R_1. (Result)

AT DAY: The day on which the max ERD occurs. (Result)

FINAL REC DOSE: This is the net recoverable dose remaining at the last day. This also is expressed as a fraction of R_1. (Result)

FINAL UNREC DOSE: This is the total non-recoverable dose accumulated through the last day. It is expressed as a fraction of R_1. (Note: The total exposure is ten times the non-recoverable dose.) (Result)

An interpretation of the first line of Figure 1 is as follows: the assumed operational schedule was: The first period (having a protection factor of 100) extends from day 1 (i.e., 1 hour after detonation to 24 hours) through day 2 (i.e., 24+ to 48 hours after detonation). The second period with an equivalent protection factor of 10 starts on day 3 (i.e., 48+ hours) and continues through the day. Period 3, with an equivalent protection factor of 4, starts on day 4 and, since no Period 4 is specified, continues through day 365. The maximum ERD occurs on day 20 and the value of Max ERD/R_1 is 0.14041. For instance, if the reference intensity is 400r/hr at 1 hr, the peak ERD would be 56.2r. At the end of day 365, the remaining recoverable dose would be 400 x .00365, or 1.46r; and the final non-recoverable dose would be 400 x .0313, or 12.5r. The total ERD at that time would be 14r. The total accumulated dose would be 125r (i.e., 10 times the non-recoverable dose).

The exposure rate, r_i, r/day, is precalculated and inserted as an input. The computations herein are based on the decay exponent of 1.23 recommended by Moreland (ref.6). The first day's exposure was calculated on the assumption that the fallout arrived one hour after detonation. In addition, the decay exponent was assumed to hold for 365 days. Both of these assumptions introduce errors which are discussed in the "Limitations" section (page 50).

The computation used herein differs from the NCRP basic computation in that an initial four-day "non-recovery" period is not incorporated. As noted previously, NCRP computation is based in part on the assumption (ref.1, pg.86)

> "3. Recovery after a brief exposure (i.e., delivered over a period of a few seconds to 4 days) begins 4 days after the start of the exposure."

To facilitate the computation of ERD used herein, the recovery was computed for each day's exposure. As a check on the "error" introduced by this simplified approach, manual computations using the NCRP assumption were made of the ERD at daily increments for continuous exposure. These daily values are compared in Figure 2 with corresponding doses computed by the simplified approach. The difference or "error" is a maximum of about 6 per cent at 5 days after detonation, decreasing slightly thereafter. The peak ERD occurs at 5 days for the "NCRP method" and at 6 days for the method (i.e., CDRP) used herein.

In comparison with the over-all accuracy of various aspects of gamma radiation dosimetry (see ref.1, pgs. 46,47,48), the "error" resulting from deleting the assumption is not considered significant.

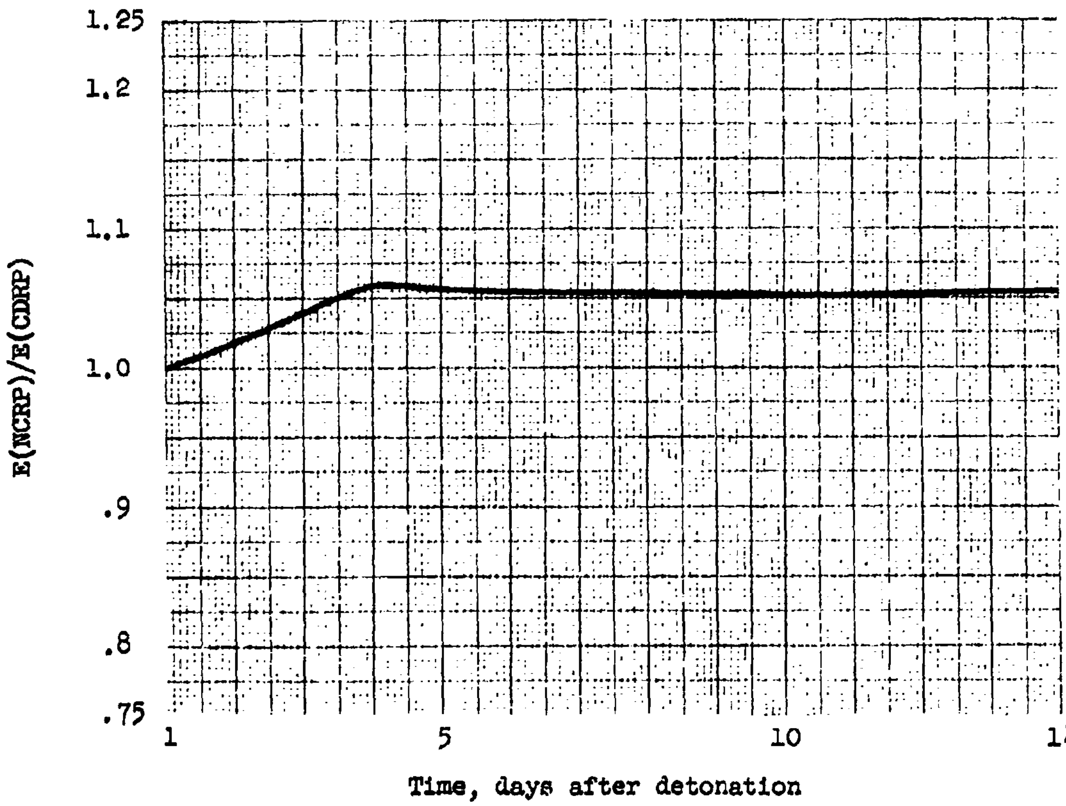

Figure 2

Comparison of equivalent residual dose computed by NCRP equation with that calculated by CDRP equation

IV. RESULTS OF COMPUTATIONS

Figure 3 shows the characteristic dose curves for continuous exposure in a fallout field with a reference intensity of 1 r/hr. Exposure is assumed to start at one hour after detonation. The total ERD gradually increases, reaching a maximum on the 6th day (i.e., between 60 and 72 hours after detonation). At this time, the daily exposure increment is equal to the daily biological recovery. Subsequent to this time, the daily dose increment is less than the recovery increment and the ERD decreases. The non-recoverable dose and the not-recovered, recoverable dose are also shown. The total accumulated exposure at any time can be determined by multiplying the unrecoverable dose by 10.

In addition to the simple operational situation of continuous exposure to fallout radiation (Figure 3), the situation of entering the fallout area at some time after the arrival of the fallout* is of interest. The results of a number of computations of this basic situation are given in Figure 4 where the peak ERD, E′, is plotted versus time of entry into the fallout area or, in effect, the stay-time in a hypothetical shelter. Also shown is the "Time of Maximum ERD" and the "Total Accumulated Dose." Since the chart is based on a reference radiation intensity of 1 r/hr, the dose values are actually "dose per unit radiation intensity." Consequently, if the reference radiation intensity of interest is 500 r/hr, the dose values should be multiplied by 500. For instance, assume a reference radiation intensity of 500 r/hr and a stay-time in the shelter of 5 days (i.e., until 96 hours after detonation). The total accumulated exposure during the year would be 500 x 0.9 or 450r. The maximum ERD would be 500 x .34 or 170r. The peak would occur

* This situation is computed by assuming that being outside the fallout area is equivalent to being in a very effective shelter. Consequently, during the initial period a protection factor of 9999 was used in the calculation for Figure 4.

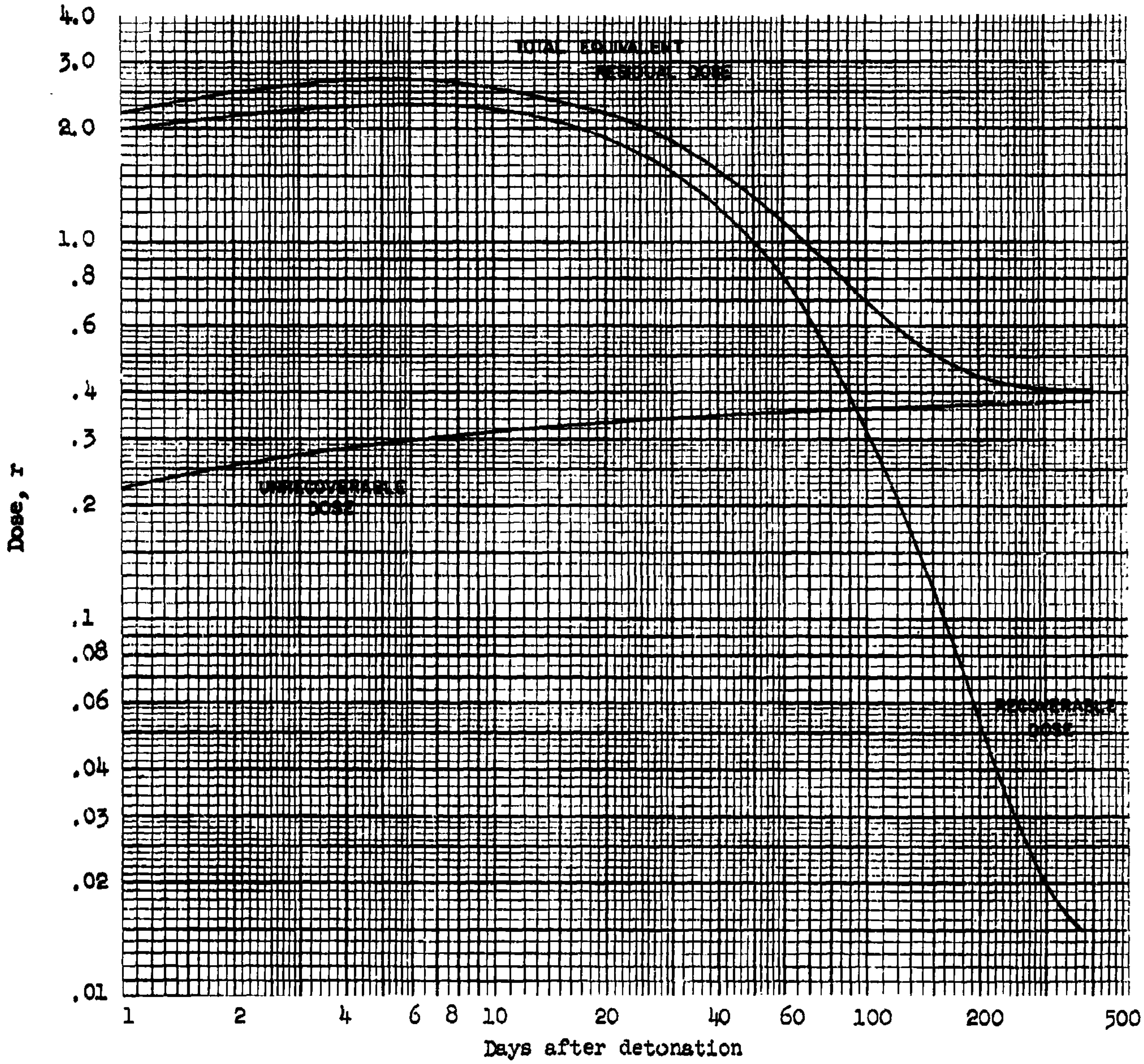

Figure 3

ERD buildup for continuous exposure in a fallout radiation field, $R_1 = 1$ r/hr

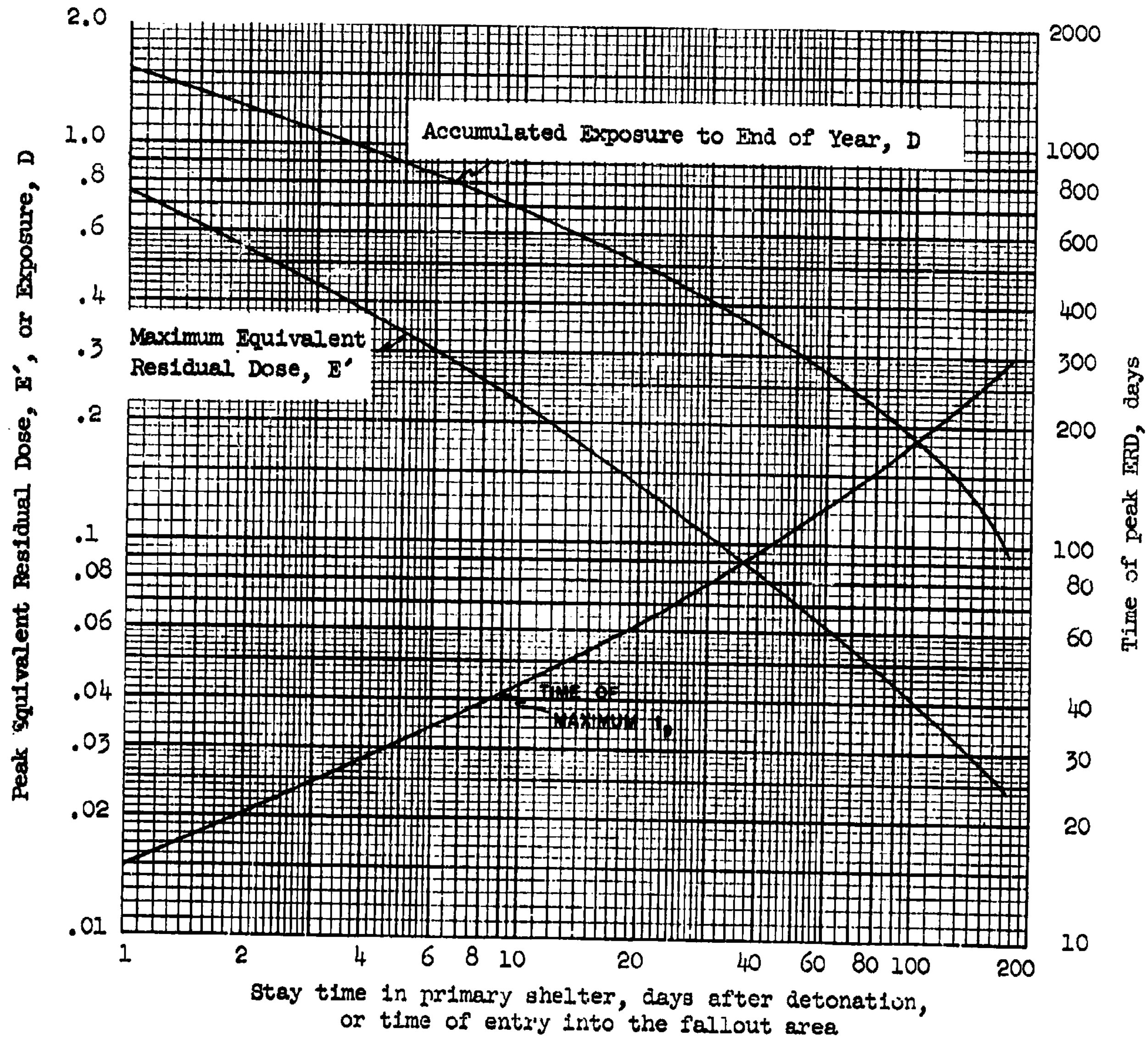

Figure 4

Peak ERD and accumulated exposure for various entry times and reference radiation intensity of 1 r/hr

$Pf_1 = 9999 \qquad Pf_2 = 1$

31 days after detonation.

More realistic operational situations may involve the progressive "movement" from one shelter situation to another, each situation providing less protection than the previous. Actual physical movement from one shelter to another may be involved in the various operational phases, although the protection factor may also change because of a change in regimen. For instance, if personnel institute a one-hour-a-day reconnaissance from the shelter, the equivalent protection factor* will change. The computational procedure can accommodate daily changes in equivalent protection factor, although it reports only the peak ERD calculated. A typical dose history for a three-phase situation is given in Figure 5. The first-period values are taken from Figure 3. The second period maximum and the third period maximum and final values were calculated; other points were estimated.

As a part of the primary objectives of the study, many computations were made. Initially, two-period (or two-stage) situations were computed. About 570 operational situations were assumed, using equivalent protection factors for the first period that ranged from 10 to 1000. The stay-time in the primary shelter and the effective protection for the second period were varied. The peak dose ratios, E'/R_1, are plotted versus the stay-time in Figures 6a, b and c. The corresponding times of peaks are given on Figures 7a through d.

An example of the use of the charts is as follows: Given a reference intensity, R_1, of 1000 r/hr and a permissible maximum equivalent residual dose, E', of 150r, the maximum permissible dose ratio, E'/R_1, is calculated

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* The equivalent protection factor is a means of using a single factor to describe the "average" protection over a 24 hour or longer period. It is the same as the "equivalent attenuation factor" defined and used by Devaney (ref.7). Appendix A gives the basic equation for its derivation and gives graphical solutions for three standard operational situations.

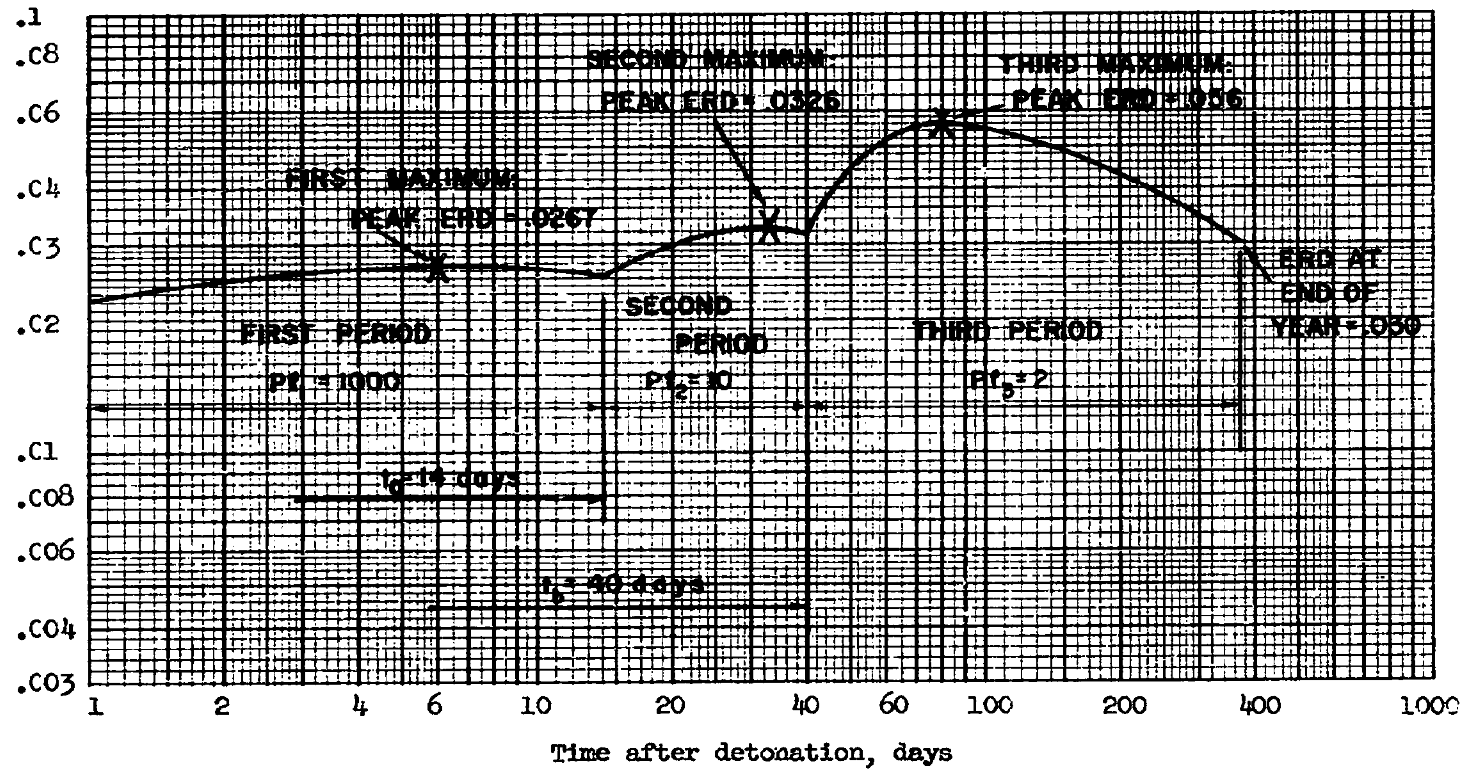

Figure 5

Typical dose (ERD) history for personnel
in a three-stage operational situation

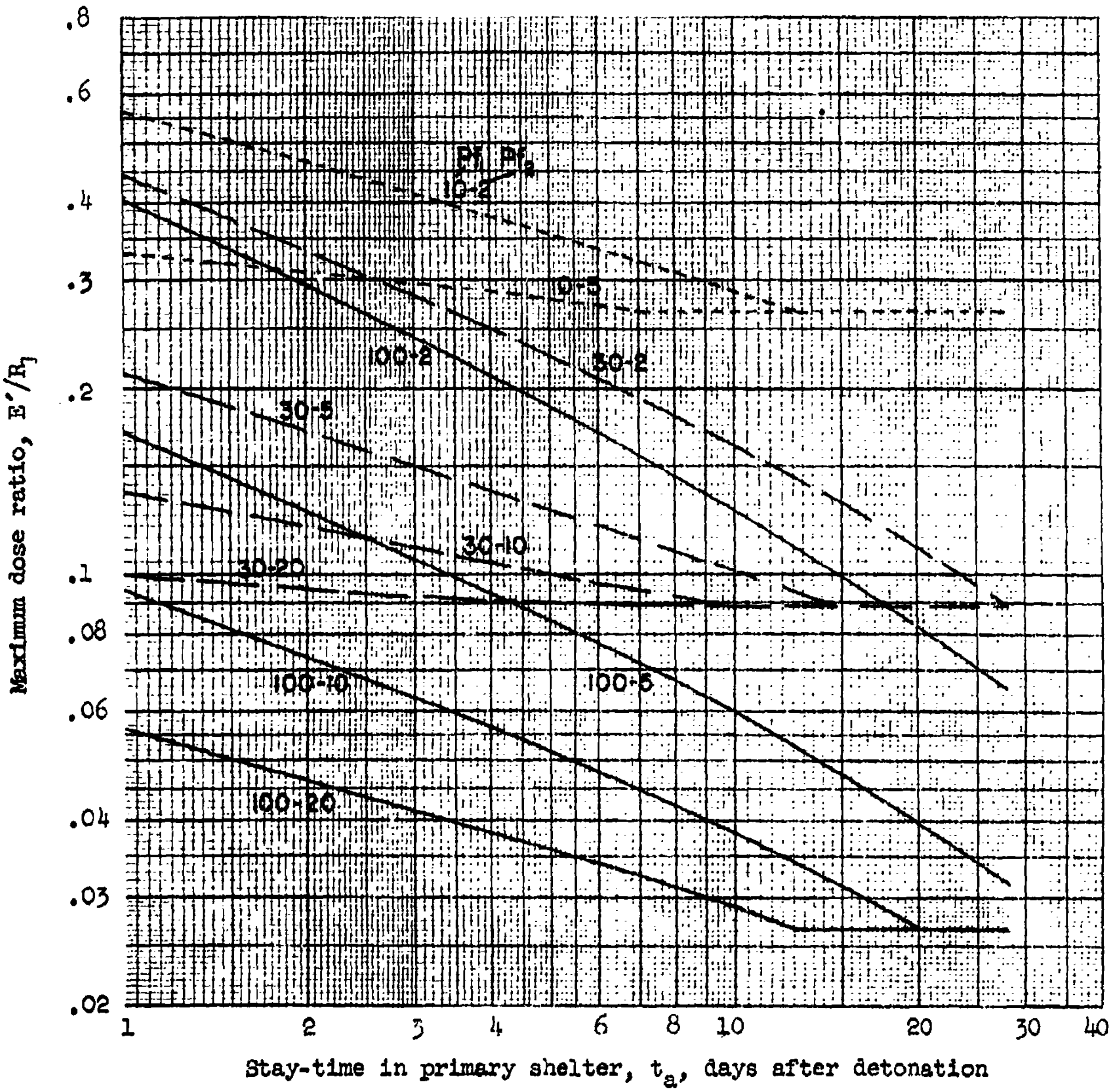

Figure 6a

Maximum dose ratio associated with
two stages of protection and various stay-times:
(10-2, 5; 30-2 to 20; 100-2 to 20)

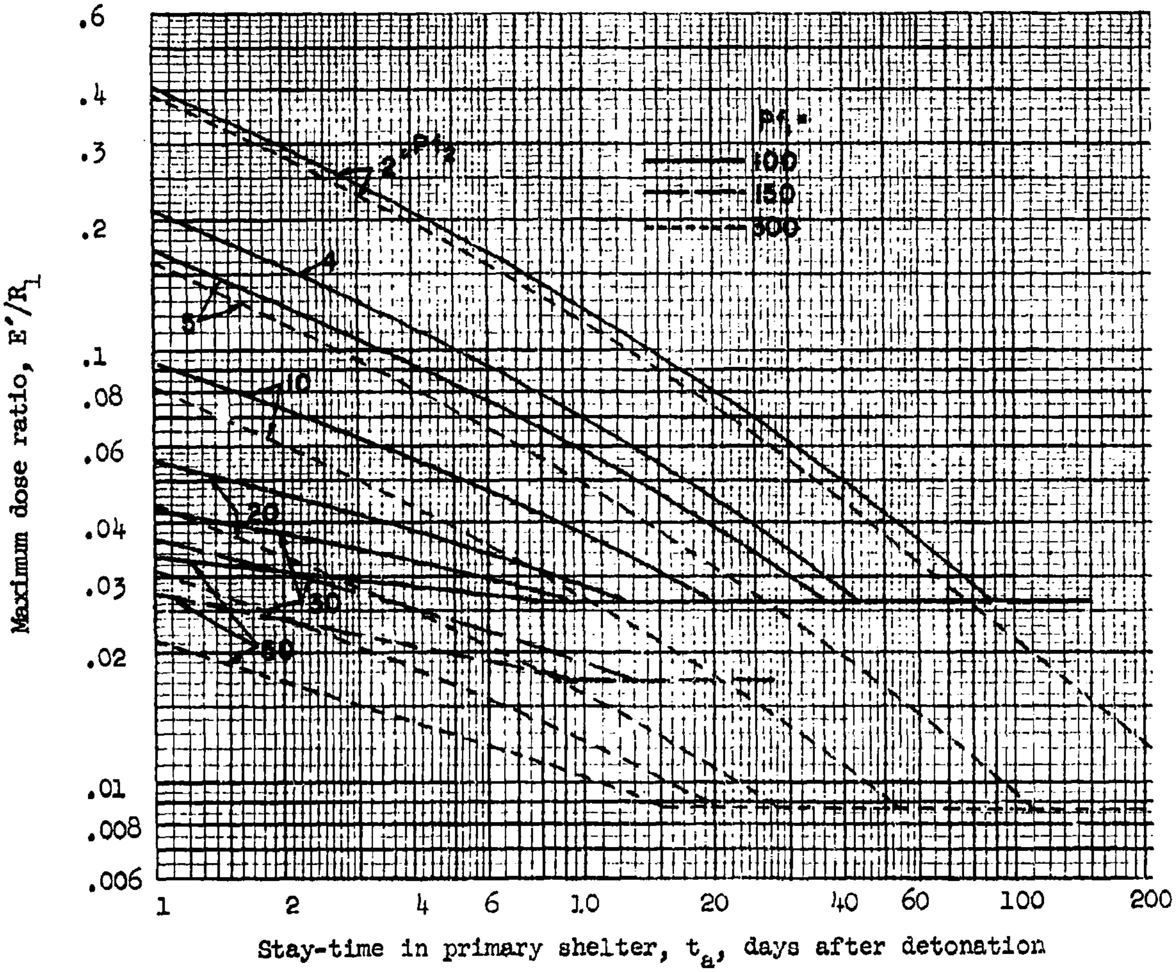

Figure 6b

Maximum dose ratio associated with
two stages of protection and various stay-times:
(100-2 to 50; 150-30, 50; 300-2 to 50)

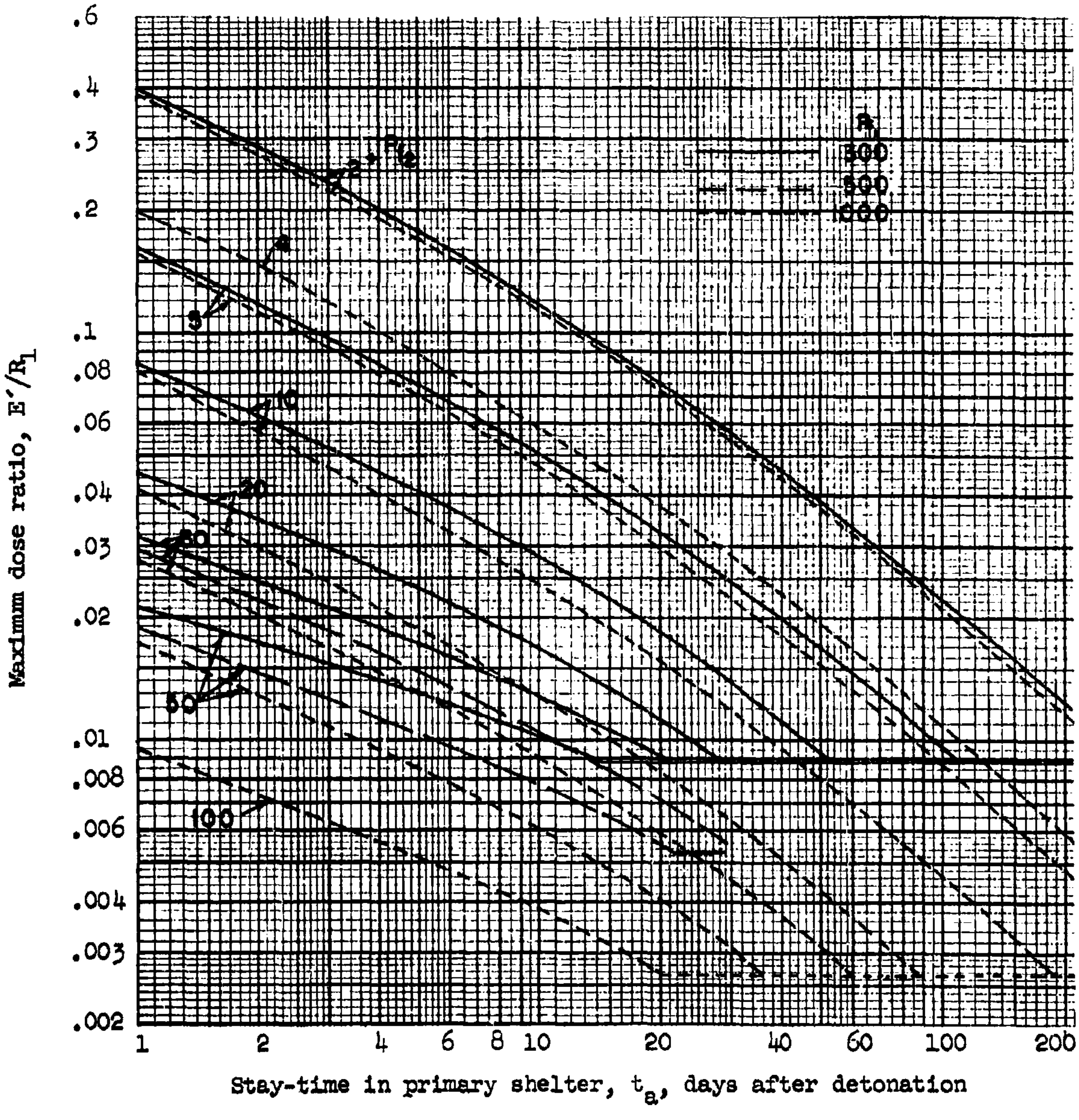

Figure 6c

Maximum dose ratio associated with
two stages of protection and various stay-times:
(300-2 to 50; 500-30, 50; 1000-2 to 100)

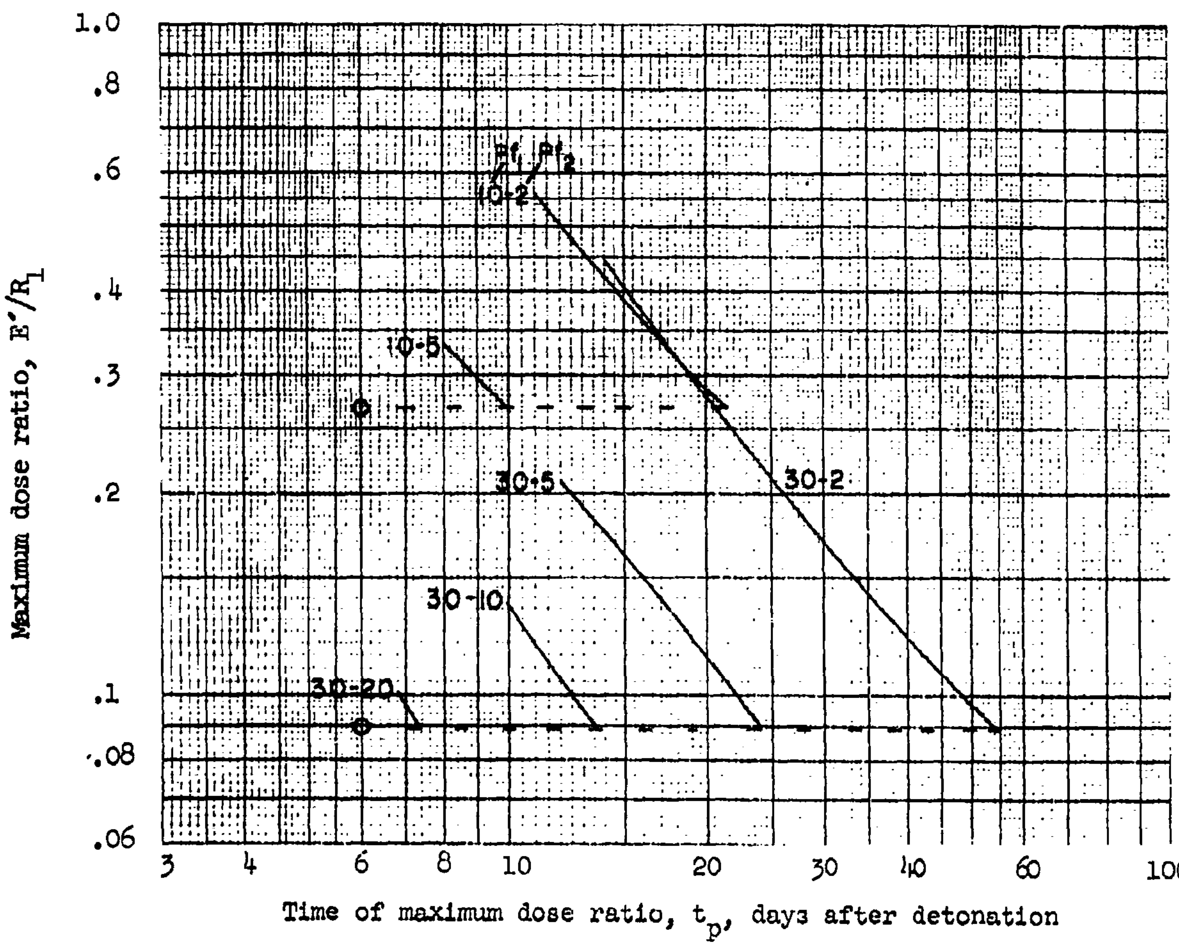

Figure 7a

Time of maximum dose ratio associated with protection and stay-time for:
10-2, 5
30-2 to 20

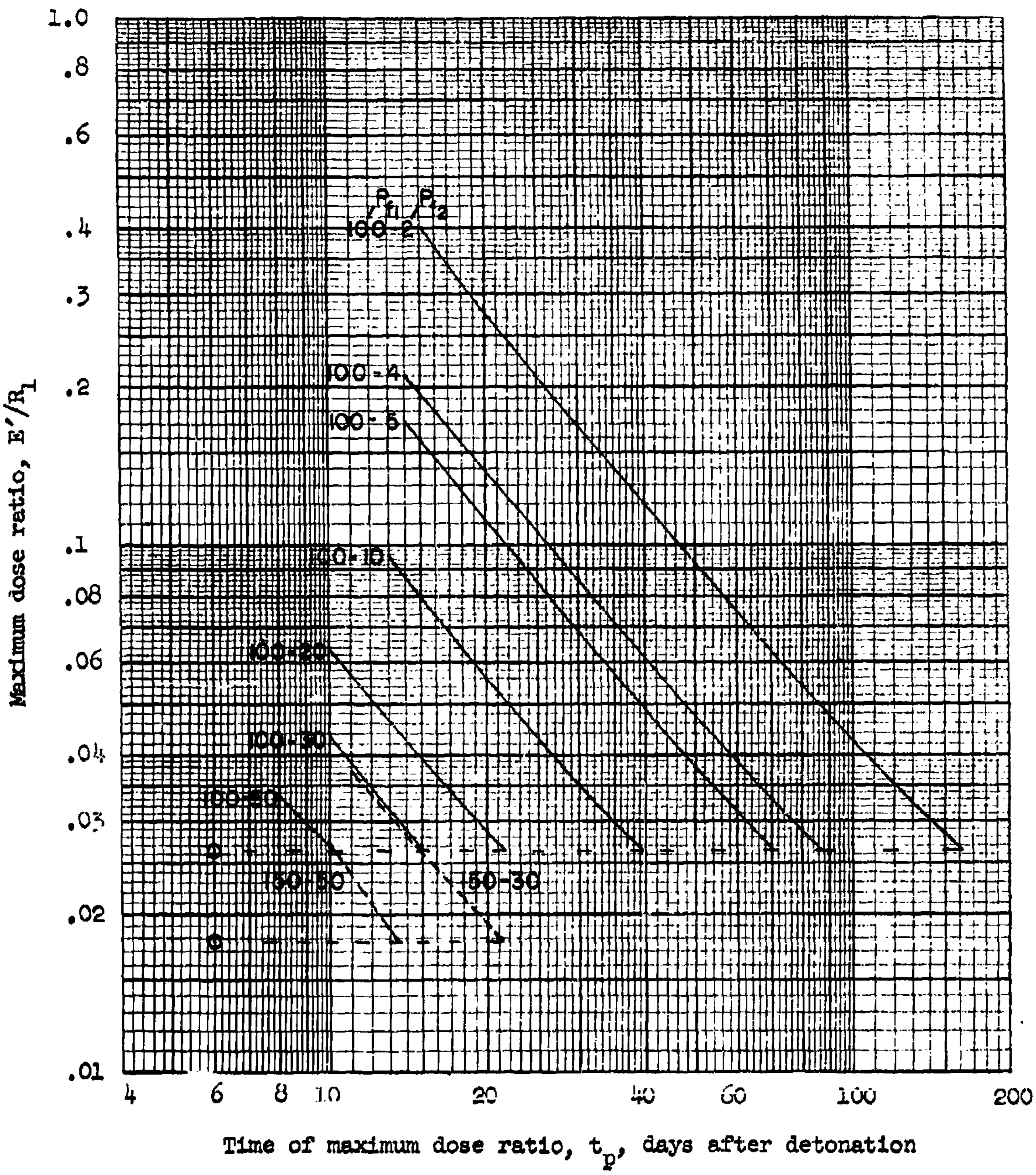

Figure 7b

Time of maximum dose ratio associated with protection and stay-time for:
100-2 to 50
150-30, 50

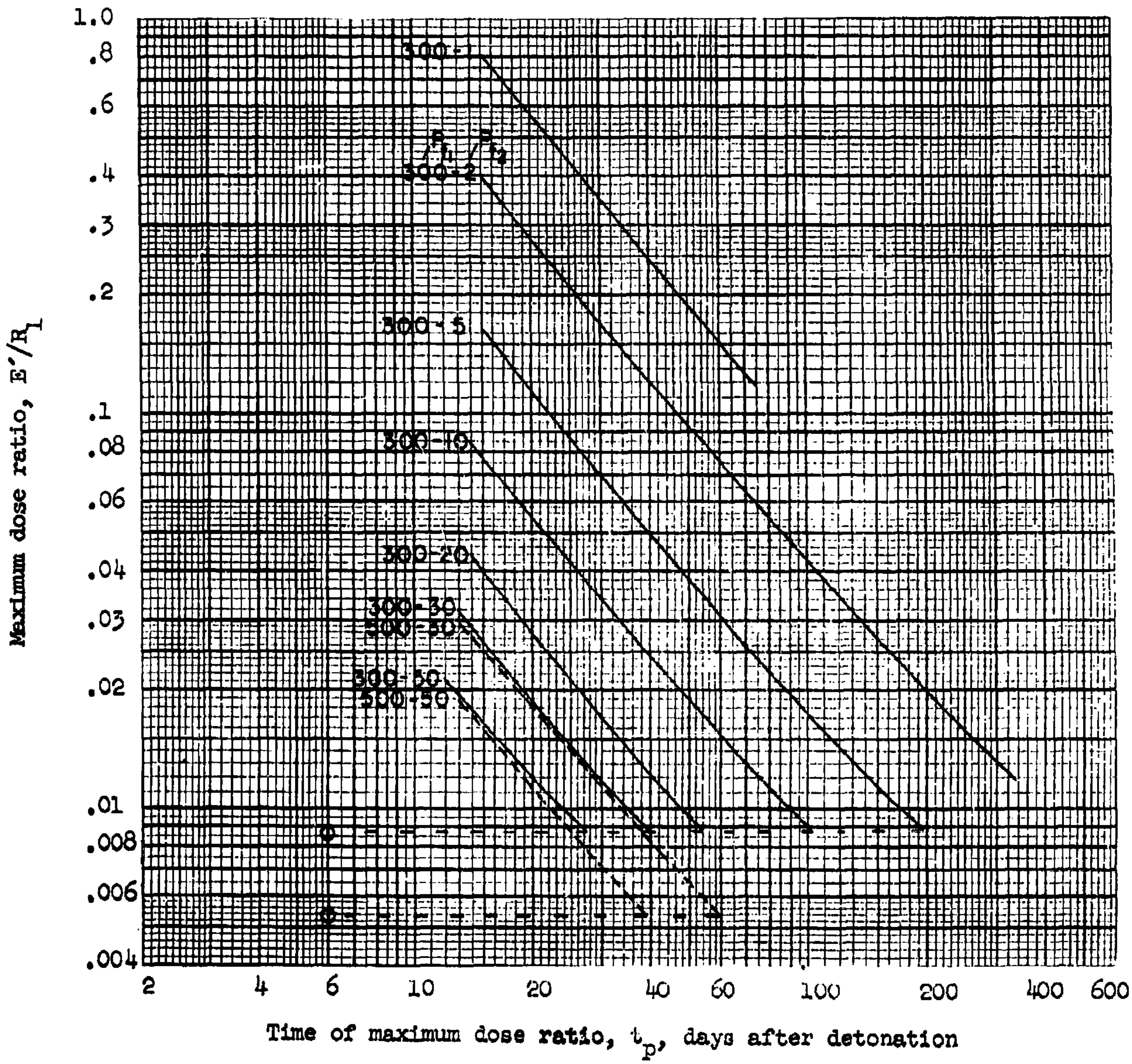

Figure 7c

Time of maximum dose ratio associated
with protection and stay-time for:
300-1 to 50
500-30, 50

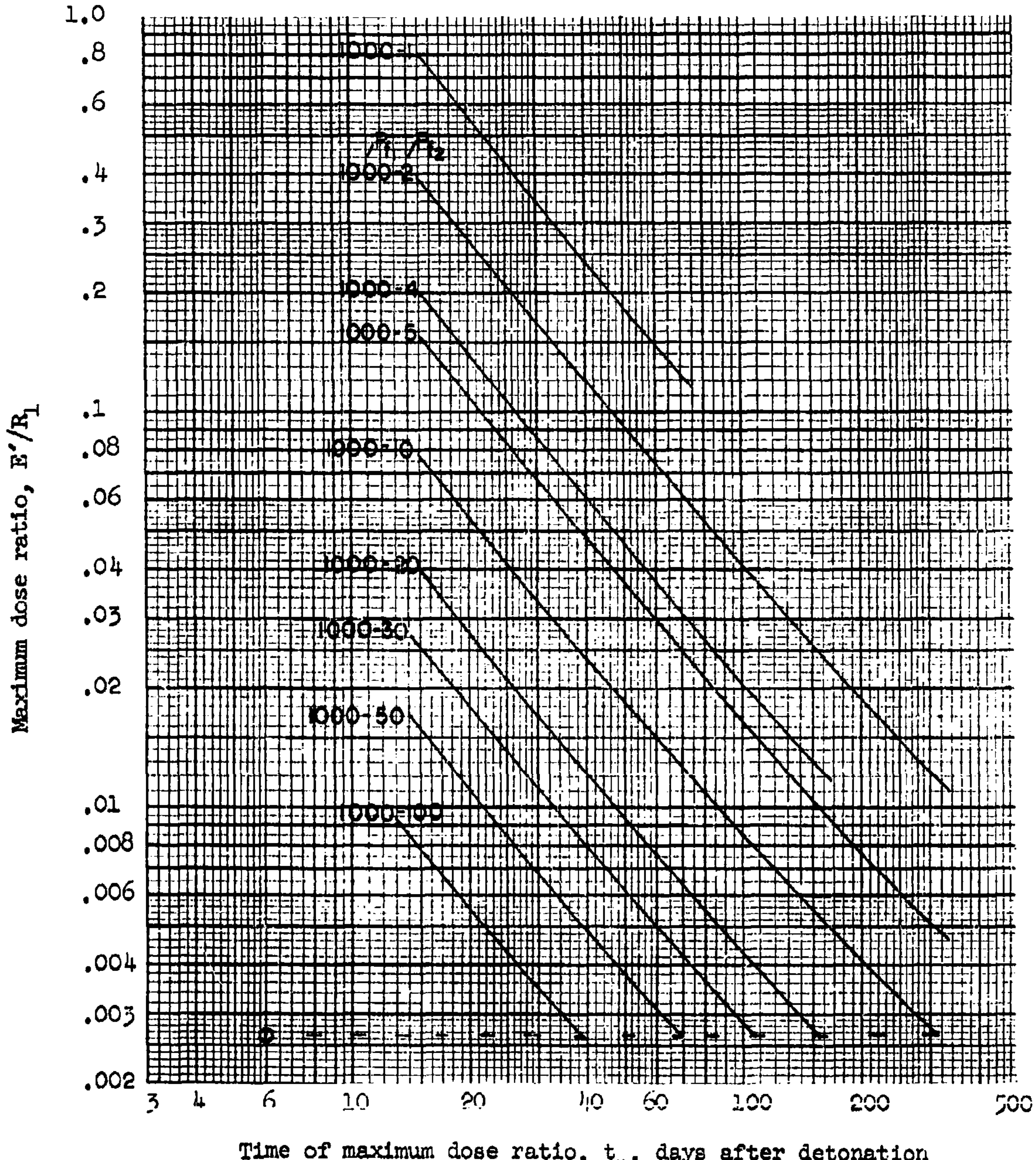

Figure 7d

Time of maximum dose ratio associated
with protection and stay-time for:
1000-1 to 100

(manually) as .15. The stay-times in the primary shelter and time of peak exposure encountered in various shelter systems are:

Pf_1	Pf_2	Stay-time, days	Ref.	Time of peak	Ref.
30	2	12	6a	33	7a
30	5	3	6a	16	7a
100	2	7.5	6b	33	7b
100	4	2.2	6b	18.5	7b
100	5	1.4	6b	15.5	7b
300	2	6.5	6b	33	7c
300	5	1.2	6b	16	7c
1000	2	6.2	6c	33	7d
1000	4	1.9	6c	19	7d
1000	5	1.1	6c	15.5	7d

The maximum dose ratio curves show a characteristic decrease in dose as the stay-time in the primary shelter increases. However, at some time the maximum dose ratio obtained in the second shelter stage will become equal to that obtained in the primary shelter stage (see Figure 5). For greater primary shelter stay-times, the maximum dose occurs in the primary shelter and, although the stay-time may increase, the maximum dose remains constant. This condition is shown also in the "time of peak" curves, where the time that the peak ratio occurs increases as stay-time increases (i.e., maximum dose ratio decreases) until the maximum dose ratio occurs during the primary shelter period. At that point, the "time of peak" becomes six days.

In the table (i.e., example) above, a fairly close correlation between the secondary protection factor, Pf_2, and the Time of Peak ERD can be noted.

This suggests that it may be possible to combine Figures 7a, b, c and d without a significant loss of accuracy.

Three-stage operational situations appear to be applicable to many post-attack operational environments. For instance, personnel might be confined to the primary shelter for a period, move to a near-by secondary shelter that provides more space and/or work facilities for the second period, and finally move back to their dwellings for the final period. Almost 600 standard situations were assumed and computations made of the maximum equivalent residual dose, time of maximum dose, etc. These results have been plotted on Figures 8a through 8f and 9a through 9f. The use of these charts is similar to that described for the two-stage charts.

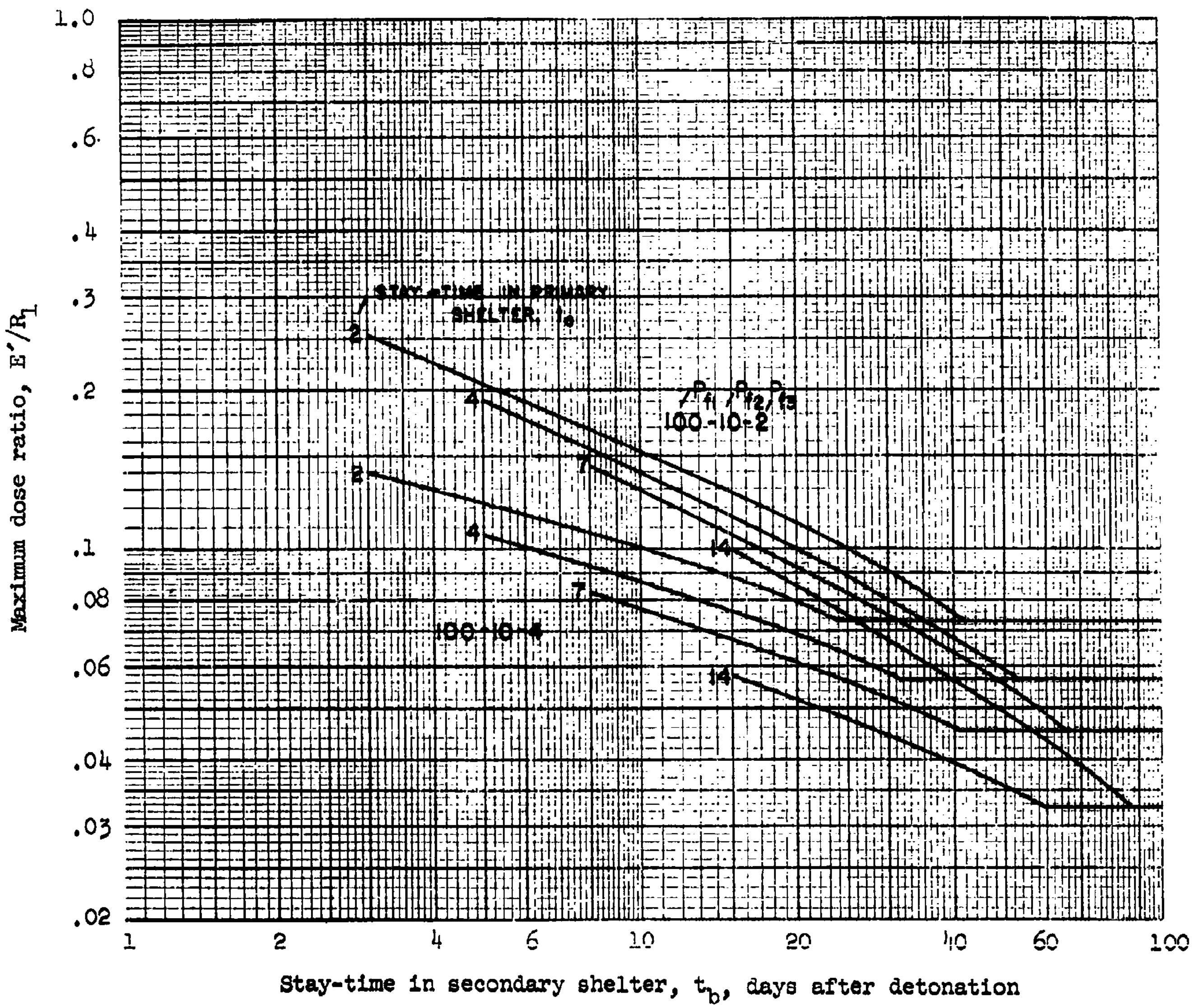

Figure 8a

Maximum dose ratio associated with three stages of protection and various stay-times. (100-10-2, 4)

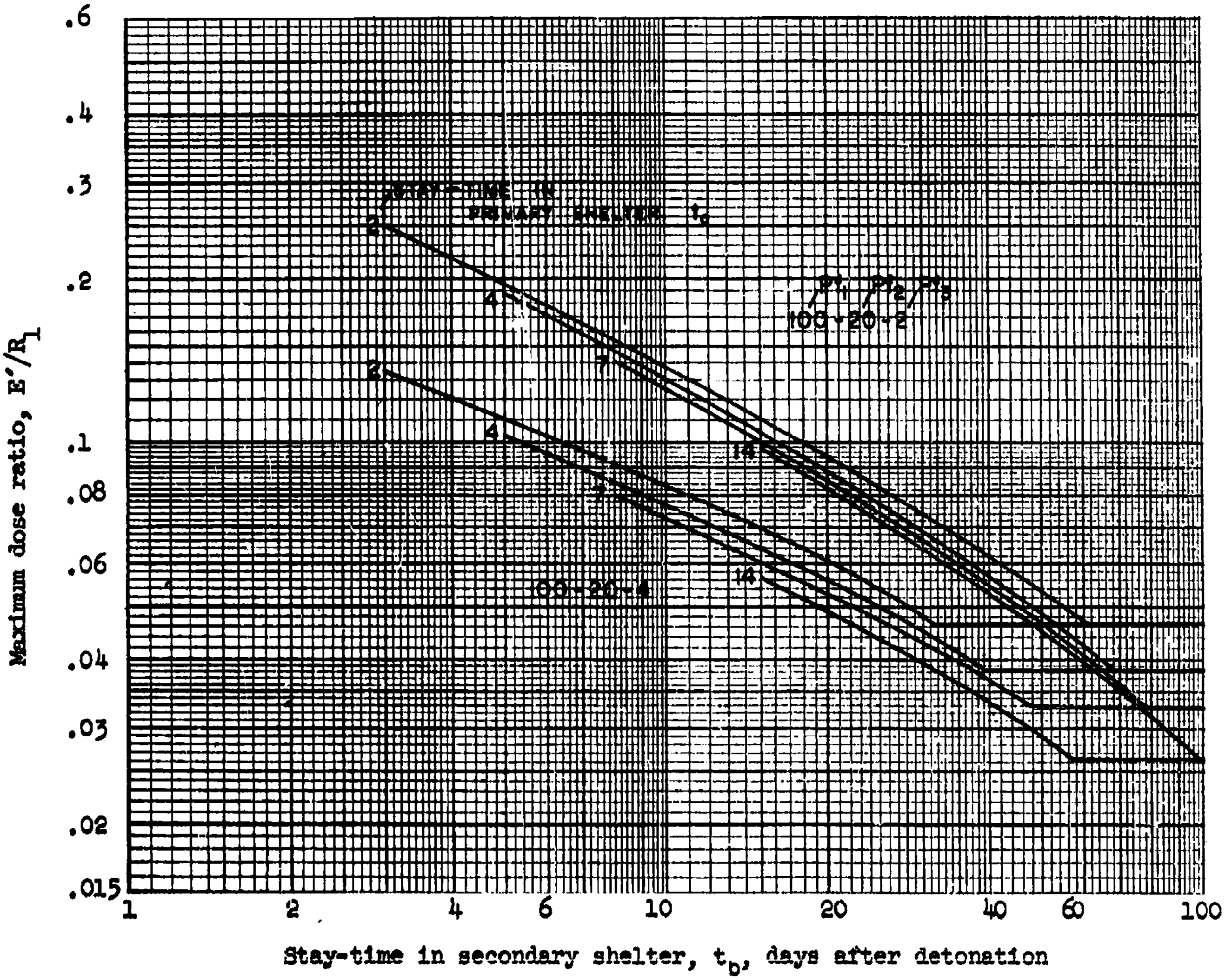

Figure 8b

Maximum dose ratio associated with three stages of protection and various stay-times. (100-20-2, 4)

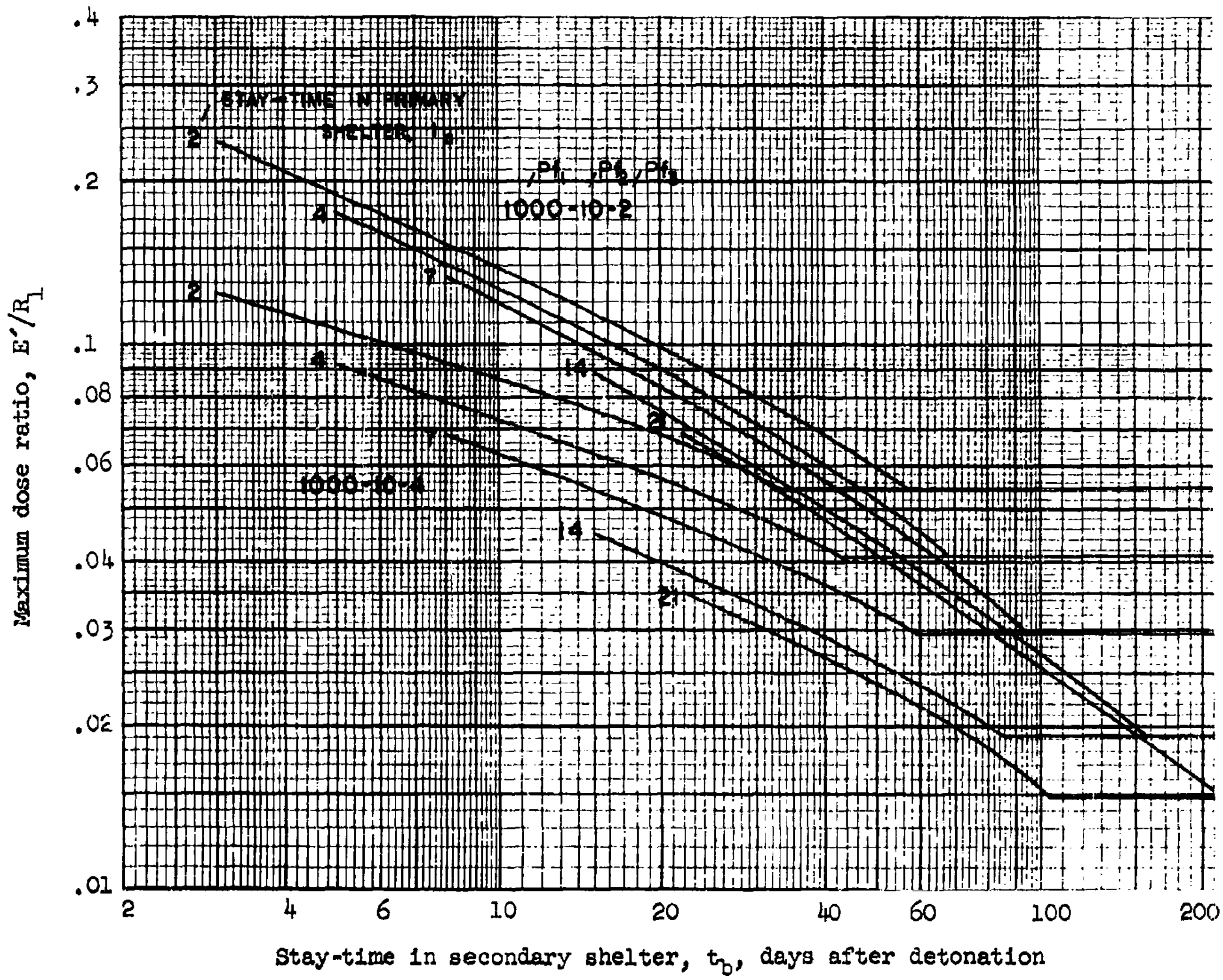

Figure 8c

Maximum dose ratio associated with three stages of protection and various stay-times. (1000-10-2, 4)

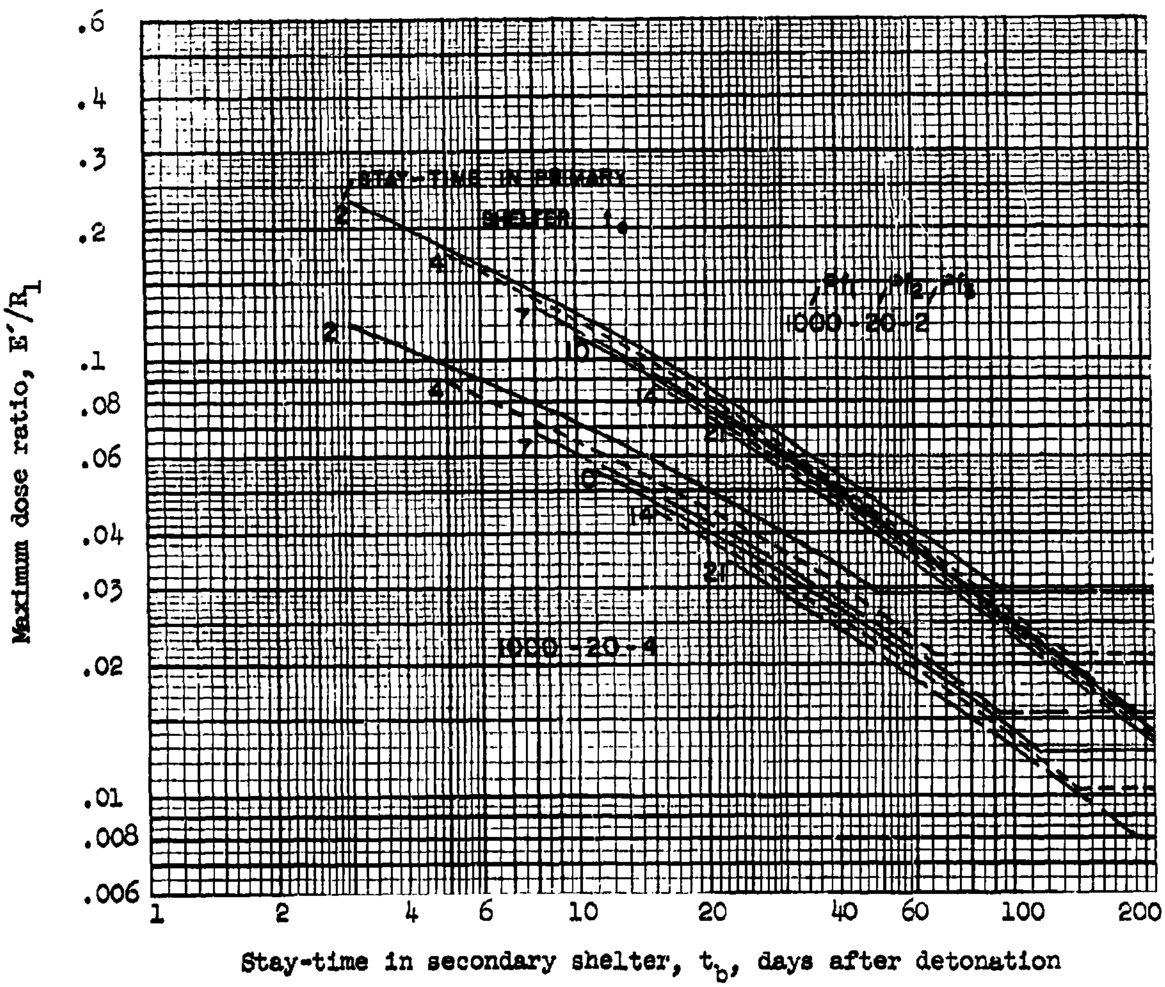

Figure 8d

Maximum dose ratio associated with three stages of protection and various stay-times. (1000-20-2, 4)

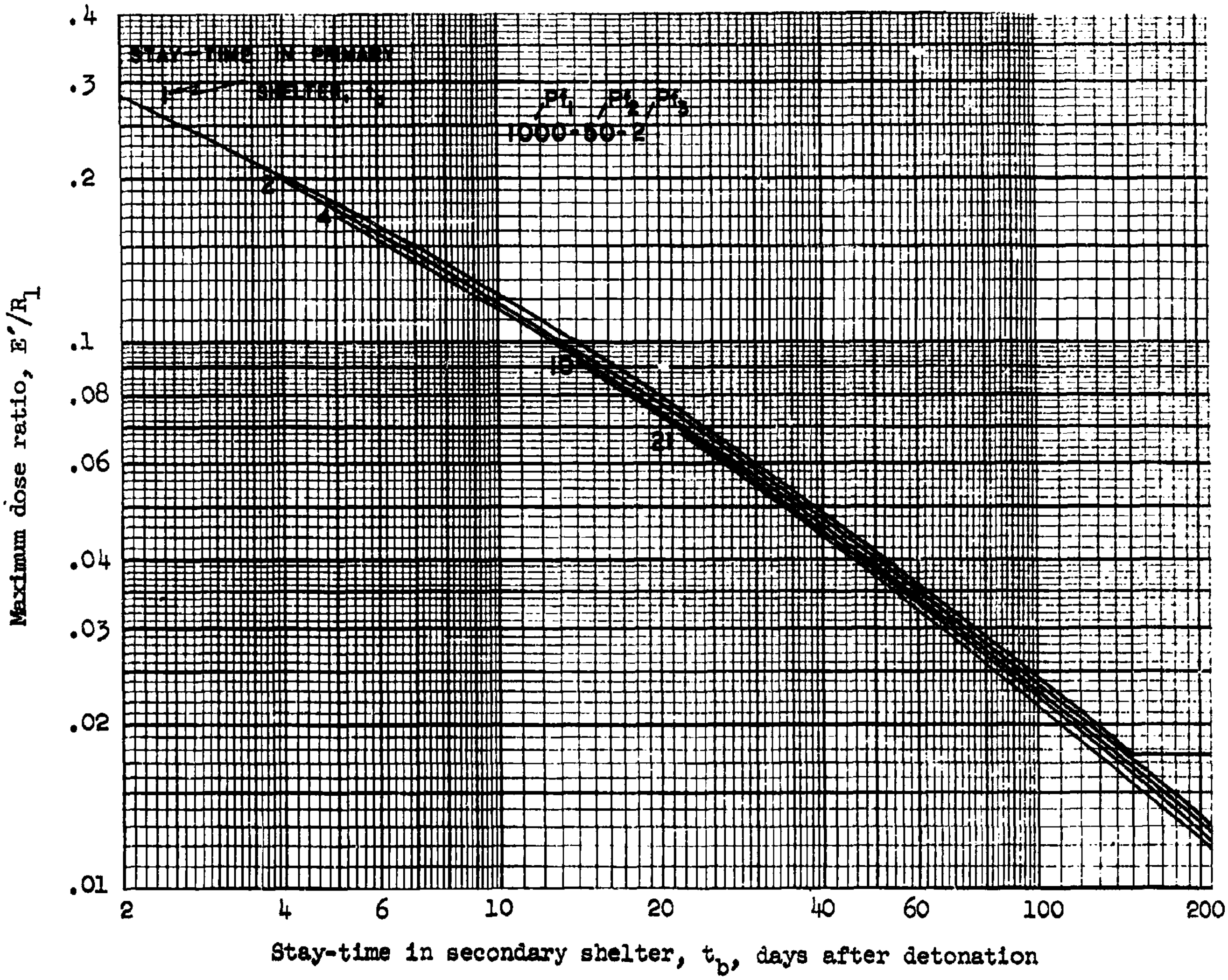

Figure 8e

Maximum dose ratio associated with three stages of protection and various stay-times. (1000-50-2)

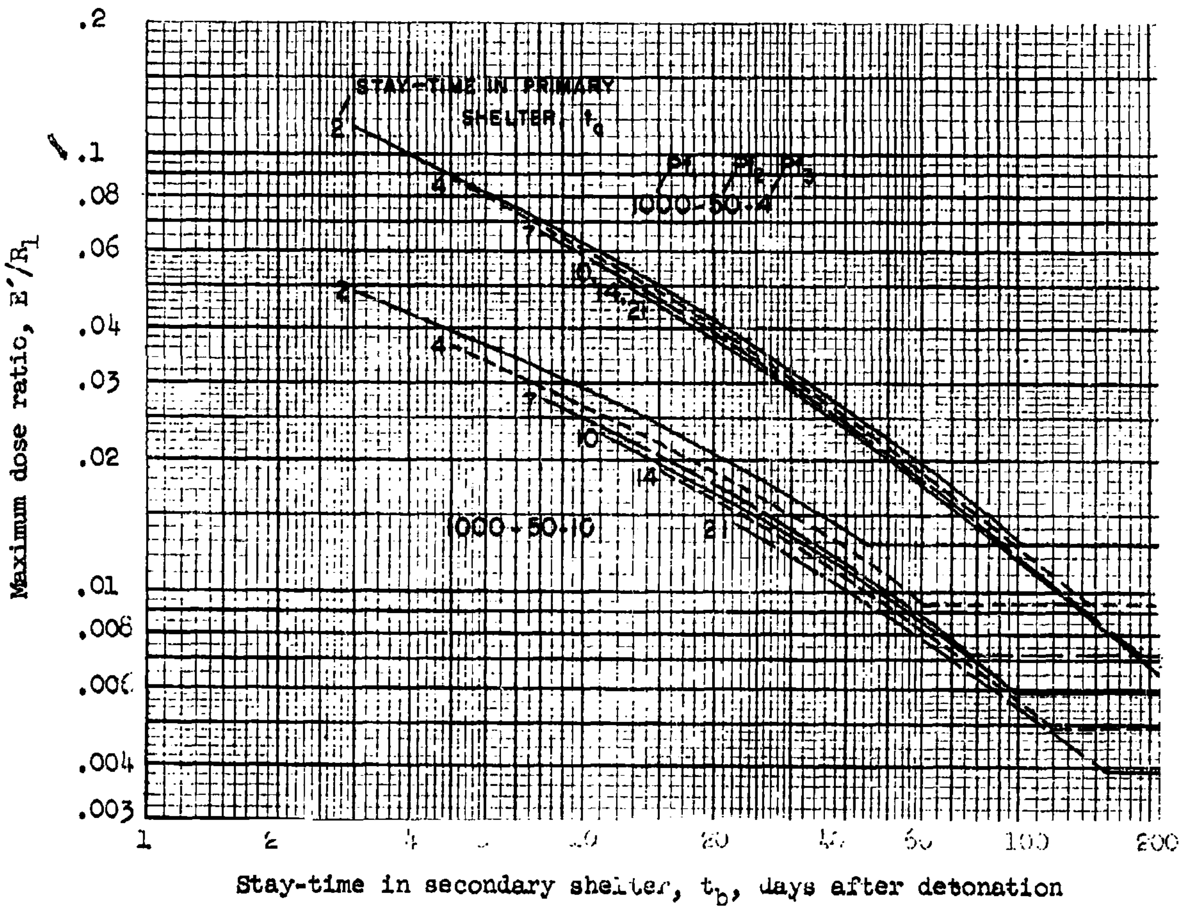

Figure 8f

Maximum dose ratio associated with three stages of protection and various stay-times. (1000-50-4, 10)

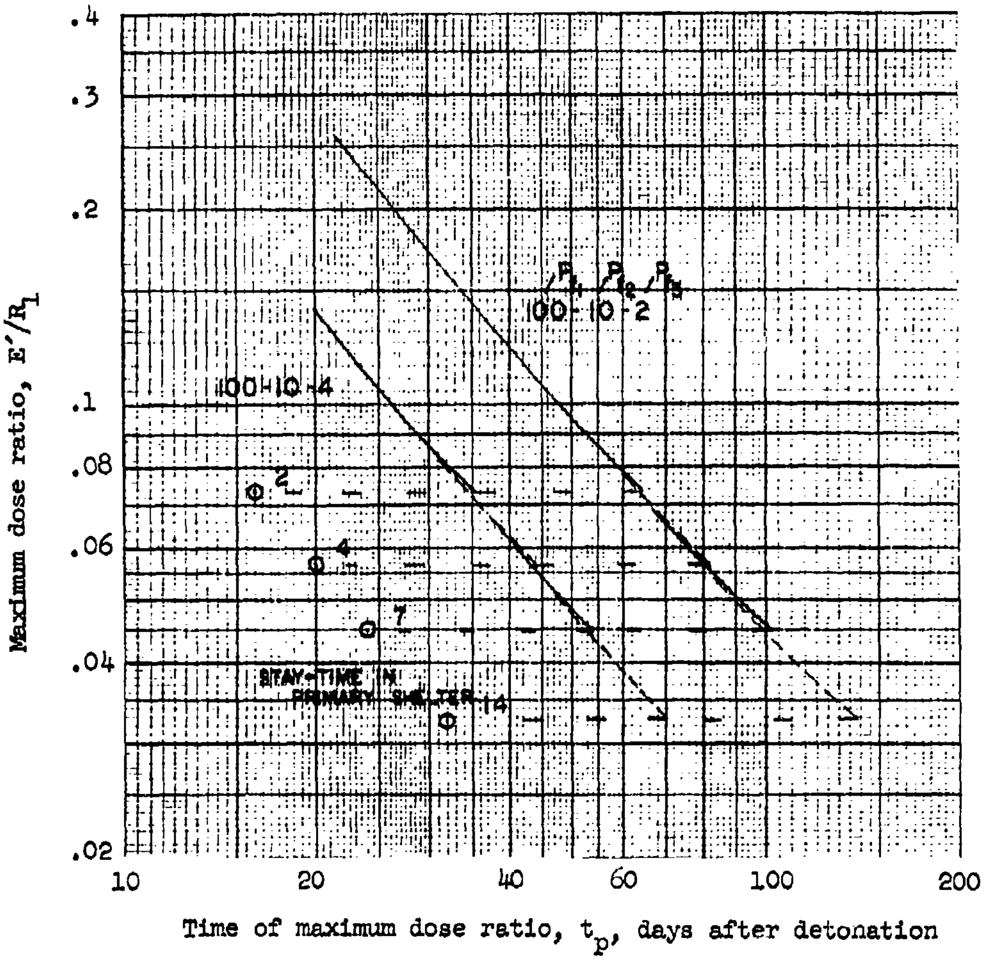

Figure 9a

Time of maximum dose ratio associated
with protection and stay-time for:
100-10-2, 4

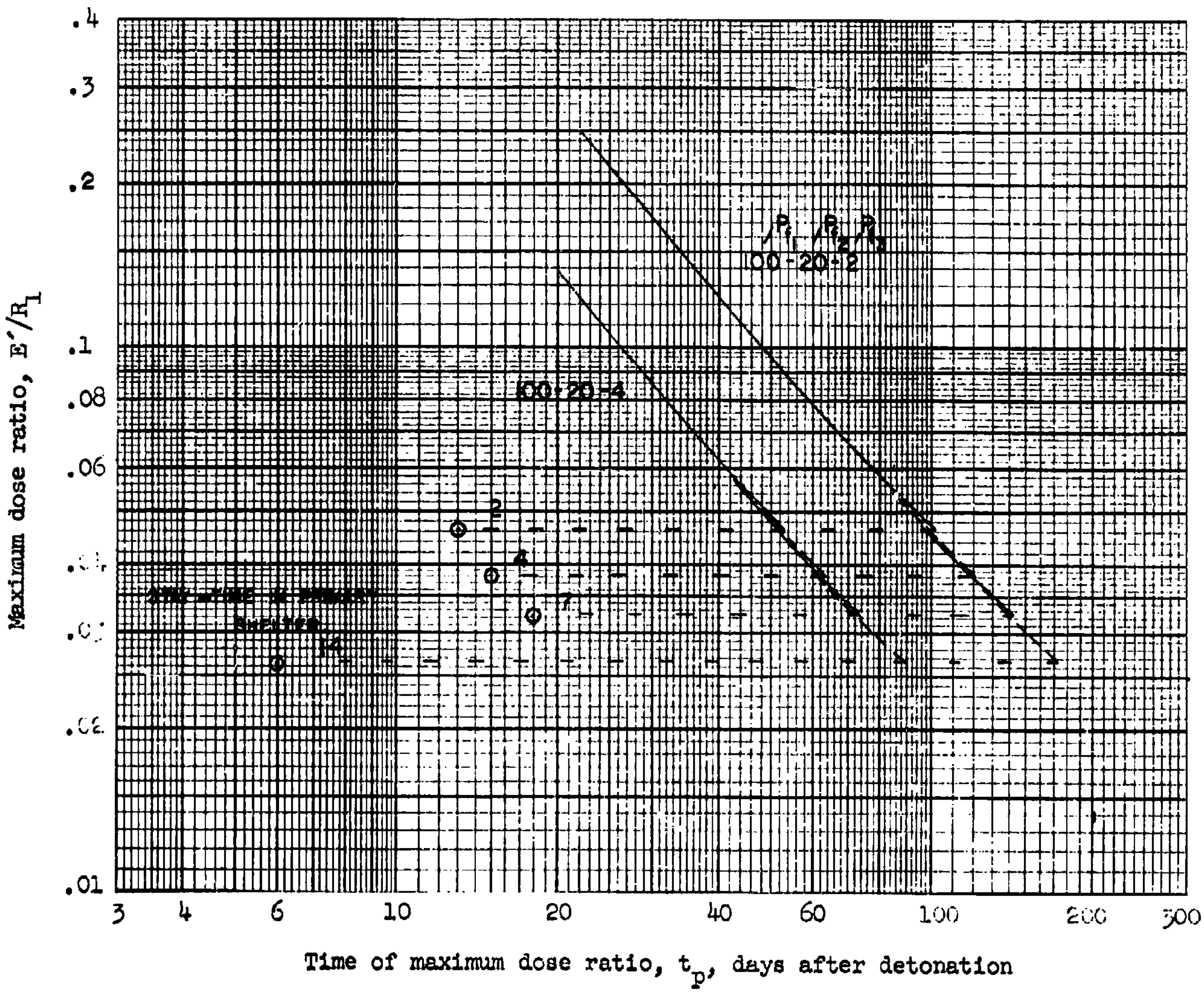

Figure 9b

Time of maximum dose ratio associated
with protection and stay-time for:
100-20-2, 4

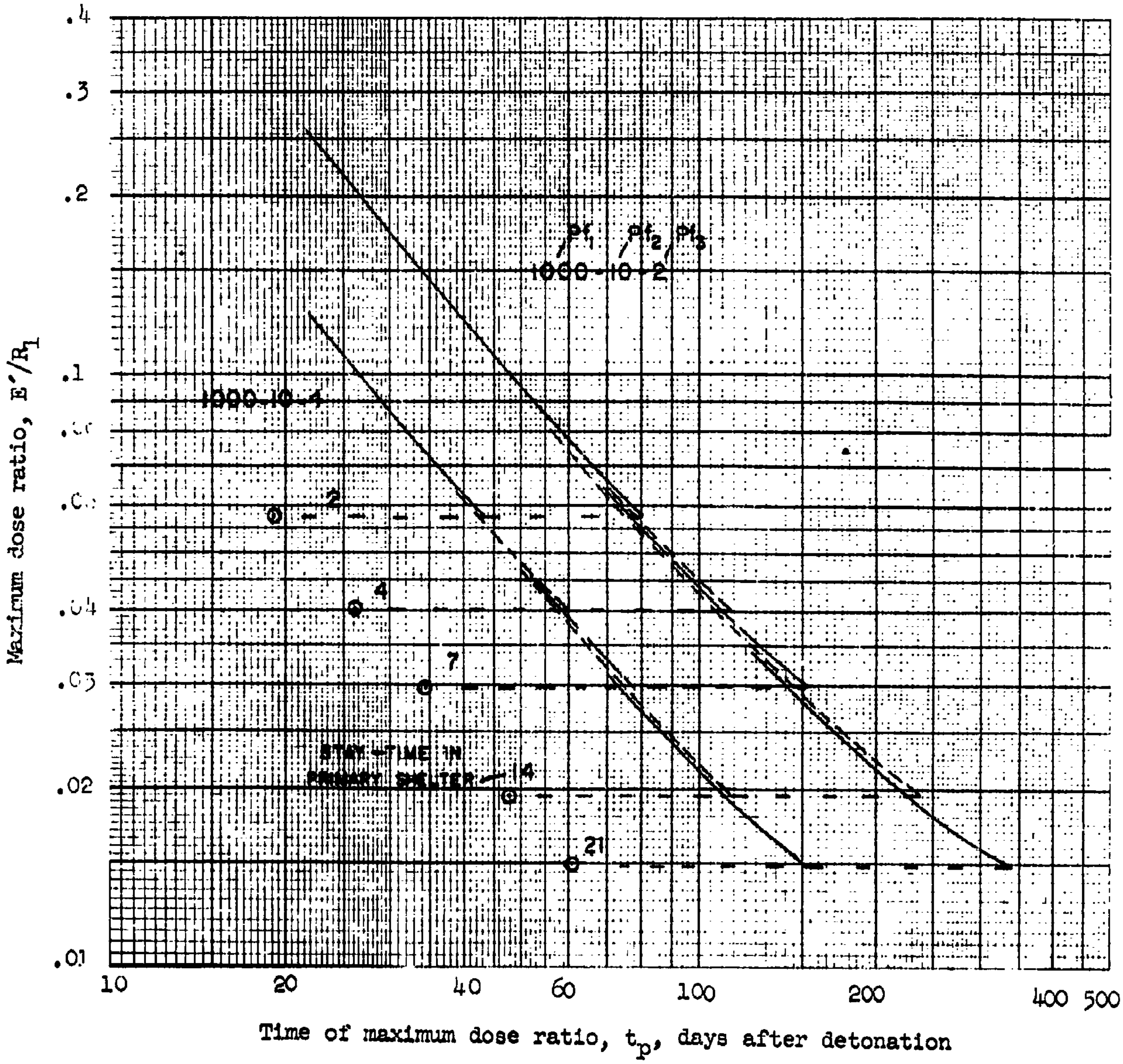

Figure 9c

Time of maximum dose ratio associated with protection and stay-time for: 1000-10-2, 4

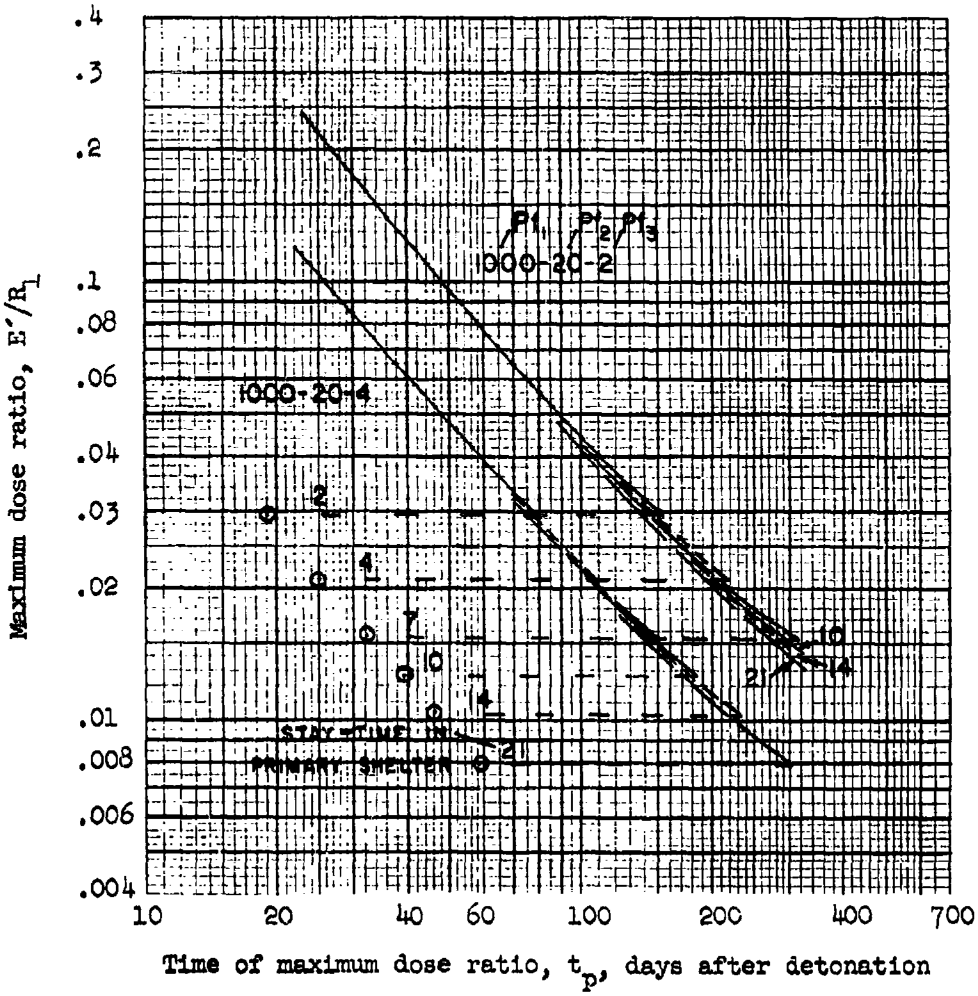

Figure 9d

Time of maximum dose ratio associated with protection and stay-time for: 1000-20-2, 4

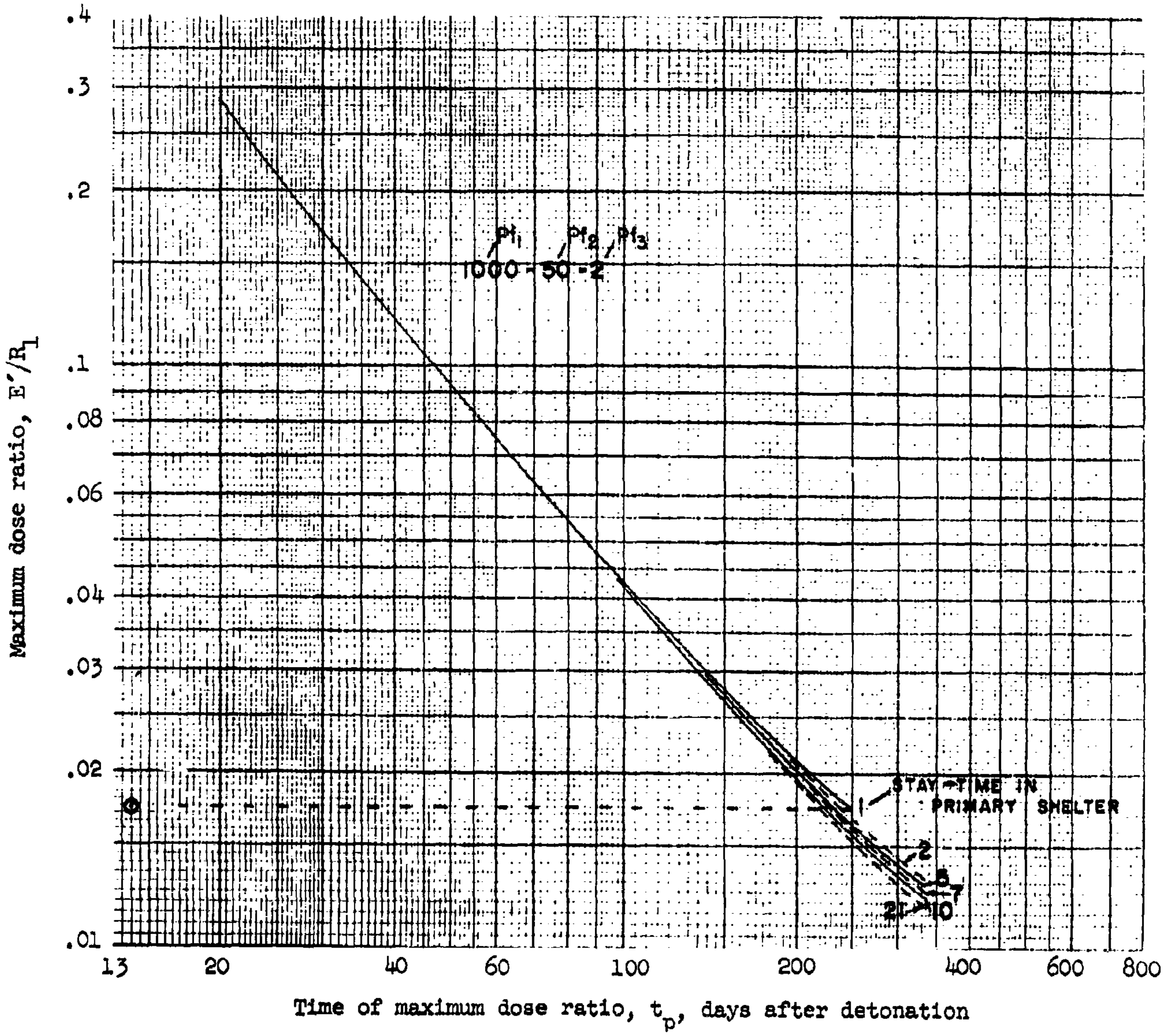

Figure 9e

Time of maximum dose ratio associated with protection and stay-time for: 1000-50-2

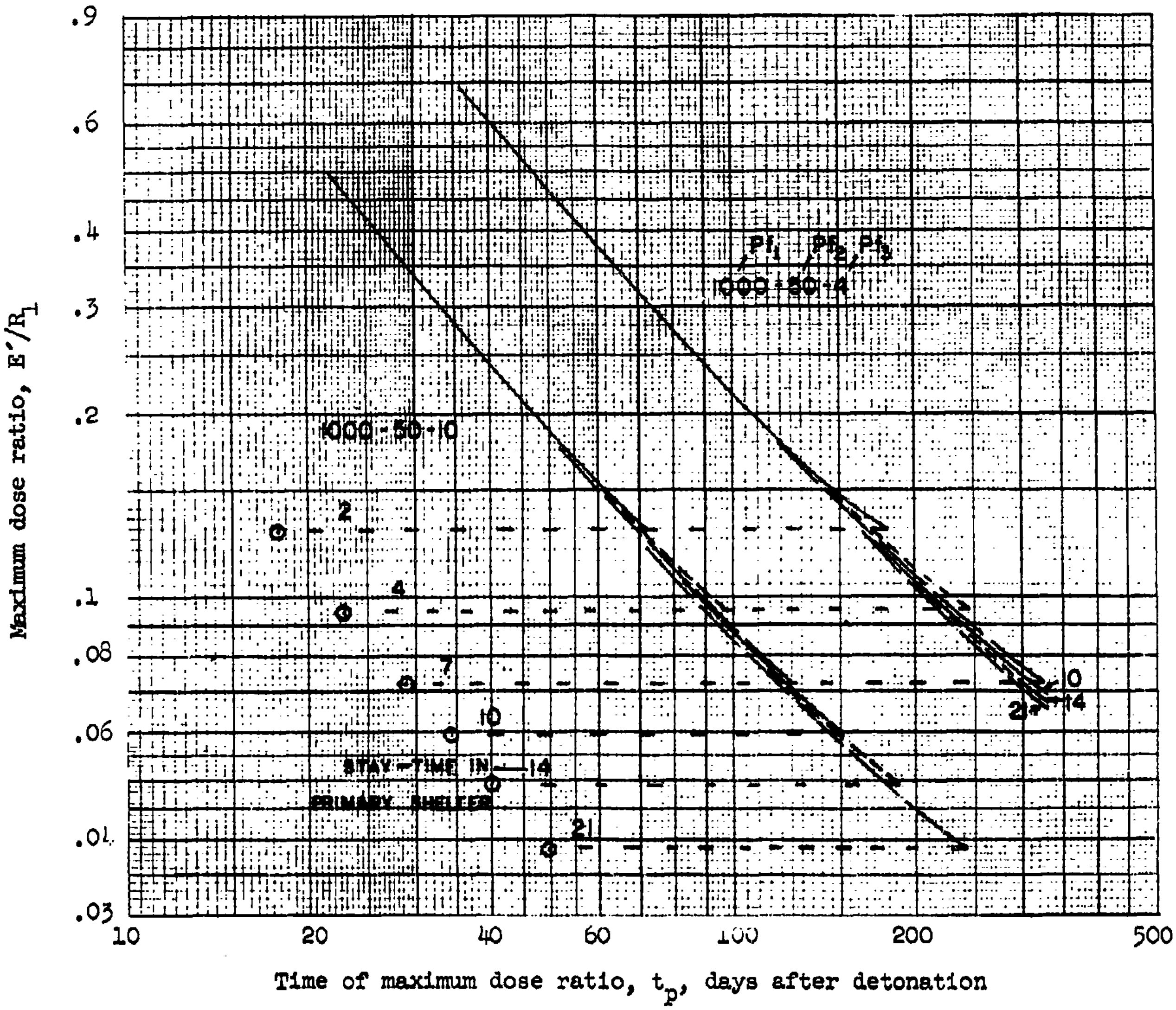

Figure 9f

Time of maximum dose ratio associated
with protection and stay-time for:
1000-50-4, 10

V. APPLICATION OF RESULTS AND CONCLUSIONS

A. Preattack Planning Tool.

The results of dose computations for selected standard situations have been reduced to tabular form to facilitate preattack planning. Table 1 gives the stay-times for situations in which the primary shelter has an equivalent protection factor of 100. Tables 2a and 2b give the same for primary protection factors of 1000. Although the tables present the same information given on the previous charts, the form provides a more rapid comparison of alternative solutions. As an example, given a permissible dose ratio, E'/R_1, of 0.05 (from, say, a reference intensity of 2000 r/hr and a maximum permissible equivalent residual dose of 100r), some of the alternative stay-time situations from Table 1 are as follows:

Pf_1	Pf_2	Pf_3	Stay-time, Primary shelter	Stay-time, Secondary shelter
100	2	-	44 days	to end of year
100	10	2	(if only 2 or 4 days, perm. dose is exceeded)	
100	10	2	if 7 days	54 days
100	10	2	14	49
100	20	2	2 14	54 44
100	4	-	18	to end of year
100	10	4	7	31
100	20	4	2 4 7 14	28 24 21 19
100	10	-	6	to end of year
100	20		1.8	to end of year
100	50		< 1	to end of year

Table 1

Shelter stay times, days after detonation, associated with different shelter systems and various exposure conditions, $Pf_1 = 100$

Pf_2	100	100				100				100
Pf_m	2	10				20				4
Pf_3		2				2				
.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.45	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.40	1.1	1.1-0	1.1-0	1.1-0	1.1-0	1.1-0	1.1-0	1.1-0	1.1-0	<1
.35	1.5	1.5-0	1.5-0	1.5-0	1.5-0	1.5-0	1.5-0	1.5-0	1.5-0	<1
.30	2.0	2.0-0	2.0-0	2.0-0	2.0-0	2.0-0	2.0-0	2.0-0	2.0-0	<1
.25	3.0	2-31	3.0-0	3.0-0	3.0-0	2-3	3.0-0	3.0-0	3.0-0	<1
.20	4.6	2-54	4-44	4.6-0	4.6-0	2-48	4-44	4.6-0	4.6-0	1.15
.15	7.8	2-10.5	4-8.6	7-7.2	7.8-0	2-8.5	4-7.8	7-7.4	7.8-0	2.2
.10	15	2-23	4-14.5	7-17	14-15	2-17.7	4-16.5	7-15.5	14-15	5.2
.09	18	2-28.5	4-24	7-21	14-18	2-21	4-19.5	7-18.5	14-17.5	6.4
.08	22	2-36	4-30	7-26	14-22.5	2-25.5	4-23.5	7-22.2	14-21.5	8.0
.07	27		4-38	7-33	14-28.5	2-32	4-29.5	7-27.5	14-26.5	10.2
.06	33		4-51	7-42	14-37	2-41	4-37	7-35	14-34	13.3
.055	38			7-48	14-43	2-47	4-42	7-40	14-38	15.5
.050	44			7-54	14-49	2-54	4-47	7-46	14-44	18
.045	50				14-57.5		4-56	7-53	14-51	21.5
.040	58				14-68		4-64	7-61	14-59	26
.035	69				14-81			7-70	14-70	31
.030	80								14-88	39
.025										
.020										
.015										
.010										
.009										
.008										
.007										
.006										
.0055										
.0050										
.0045										
.0040										
.0035										
.0030										
.0025										
.0020										

Pf_2	100				100				100	100	100
Pf_m	10				20				10	20	50
Pf_3	4				4						
.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.45	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.40	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.35	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.30	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.25	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.20	1.15-0	1.15-0	1.15-0	1.15-0	1.15-0	1.15-0	1.15-0	1.15-0	<1	<1	<1
.15	2-2.3	2.2-0	2.2-0	2.2-0	2-2.3	2.2-0	2.2-0	2.2-0	<1	<1	<1
.10	2-10	4-6.1	5.2-0	5.2-0	2-6.4	4-5.4	5.2-0	5.2-0	<1	<1	<1
.09	2-13.7	4-8.6	6.4-0	6.4-0	2-8.2	4-7	6.4-0	6.4-0	1.3	<1	<1
.08	2-21.3	4-12.5	7-8.8	8.0-0	2-11	4-9.2	7-8.2	8.0-0	1.8	<1	<1
.07		4-18	7-13	10.2-0	2-14.5	4-12.5	7-11	10.2-0	2.5	<1	<1
.06		4-27	7-19.4	13.3-0	2-19.5	4-17	7-15	13.3-0	3.8	<1	<1
.055			7-24	14-16.5	2-23	4-20	7-18	14-15.7	4.7	1.25	<1
.050			7-31	14-21	2-28	4-24	7-21	14-19	6.0	1.8	<1
.045				14-27		4-29	7-26	14-22.8	7.8	2.7	<1
.040				14-36		4-36	7-32	14-28	10	4.0	<1
.035				14-50			7-42	14-36	13.7	6.3	<1
.030								14-47	18	10	4.3
.025											
.020											
.015											
.010											
.009											
.008											
.007											
.006											
.0055											
.0050											
.0045											
.0040											
.0035											
.0030											
.0025											
.0020											

Note:

1. Stay times given in days after detonation. First number is stay time in primary shelter, second number is stay time in secondary shelter.
2. Areas having no values have no solution.

Table 2a

Shelter stay times, days after detonation, associated with different shelter systems and various exposure conditions, $Pf_1 = 1000$

P_{f_3}	1000	1000					1000					1000					1000	1000	1000	1000
P_{f_2}	2	10					20					50					4	10	20	50
P_{f_3}		2					2					2								
.50	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.45	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.40	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.35	1.25	1.25-0	1.25-0	1.25-0	1.25-0	1.25-0	1.26-0	1.25-0	1.25-0	1.25-0	1.25-0	1.25-0	1.25-0	1.25-0	1.25-0	1.25-0	<1	<1	<1	<1
.30	1.7	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	1.7-0	<1	<1	<1	<1
.25	2.4	2-2.6	2.4-0	2.4-0	2.4-0	2.4-0	2-2.6	2.4-0	2.4-0	2.4-0	2.4-0	2-25	2.4-0	2.4-0	2.4-0	2.4-0	<1	<1	<1	<1
.20	3.7	2-4.4	3.7-0	3.7-0	3.7-0	3.7-0	2-4.1	3.7-0	3.7-0	3.7-0	3.7-0	2-3.4	3.7-0	3.7-0	3.7-0	3.7-0	1	<1	<1	<1
.15	6.3	2-8.8	4-7	6.3-0	6.3-0	6.3-0	2-7.3	4-6.8	6.3-0	6.3-0	6.3-0	2-4.6	4-6.3	6.3-0	6.3-0	6.3-0	1.9	<1	<1	<1
.10	12	2-19.5	4-14	7-14	12-0	12-0	2-16	4-14.5	7-13	12-0	12-0	2-13	4-12.6	7-12.4	10-12	12-0	4	<1	<1	<1
.09	14.3	2-24	4-20	7-17.5	14-15	14.3-0	2-19	4-17	7-16	14-14.5	14.3-0	2-15.6	4-15	7-14.7	10-14.5	14.3-0	4.8	<1	<1	<1
.08	17	2-30	4-25	7-22	14-18	17-0	2-22.5	4-21	7-19	14-17.5	17-0	2-18.8	4-18	7-17.7	10-17.4	17-0	6.0	1	<1	<1
.07	21	2-38	4-31	7-28	14-23	21-21	2-27.5	4-26.5	7-24	14-22	21-21	2-23	4-22	7-21.7	10-21.3	21-21	7.4	1.3	<1	<1
.06	26	2-49.5	4-40	7-36	14-30	21-28	2-34	4-32	7-30.5	14-28	21-26.5	2-29	4-27.7	7-27.3	10-27	21-26	9.5	1.8	<1	<1
.055	29.5	2-56	4-46	7-41	14-34	21-32	2-39	4-36	7-35	14-32	21-30	2-32.5	4-31.5	7-30.7	10-30.2	21-29.6	11	2.2	<1	<1
.050	33		4-53	7-48	14-40	21-37	2-45	4-41	7-40	14-37	21-35	2-37	4-36	7-35	10-34.5	21-34	13	2.63	<1	<1
.045	39		4-61	7-56	14-47	21-44	2-52	4-48	7-46	14-43	21-40	2-43	4-41	7-40.5	10-40	21-39	15.3	3.2	<1	<1
.040	45			7-65	14-57	21-52	2-62	4-56	7-54	14-51	21-48	2-50	4-48	7-47.4	10-47	21-45.5	18	4	1.07	<1
.035	54			7-78	14-70	21-64	2-75	4-67	7-65	14-61	21-57	2-60	4-58	7-57	10-56	21-54	22.5	5.2	1.4	<1
.030	65			7-94	14-87	21-80	2-92	4-83	7-80	14-74	21-71	2-73	4-70.5	7-69	10-68.5	21-66	27.5	6.9	2	<1
.025	81				14-112	21-104		4-106	7-100	14-95	21-91	2-93	4-90	7-88.3	10-87	21-84	35	9.5	2.85	<1
.020	105				14-150	21-143			7-134	14-127	21-120	2-125	4-120	7-118	10-116	21-110	47.5	13.5	4.4	<1
.015	150									14-183	21-178	2-178	4-170	7-163	10-165	21-158	68	21	7.5	1.4
.010																	109	37	15	3.4
.009																	125	43	18	4.4
.008																	140	50	21.3	5.6
.007																	165	60	26	7.4
.006																	195	73	32	10
.0055																		81	36	12
.0050																		91	41	14.2
.0045																		105	46	17
.0040																		118	54	20.5
.0035																		138	63	25
.0030																		168	75	31
.0025																				
.0020																				

Note:

1. Stay times given in days after detonation. First number is stay time in primary shelter, second number is stay time in secondary shelter.
2. Areas having no values have no solution.

Table 2b

Shelter stay times, days after detonation, associated with different shelter systems and various exposure conditions, $Pf_I = 1000$

P_I	1000	1000					1000					1000					1000	1000				1000
P_{II}	4	10					20					50					10	50				20
P_{III}		4					4					4						10				
.50	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.45	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.40	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.35	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.30	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.25	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
.20	1	1-0	1-0	1-0	1-0	1-0	1-0	1-0	1-0	1-0	1-0	1-0	1-0	1-0	1-0	1-0	<1	<1	<1	<1	<1	<1
.15	1.9	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	1.9-0	<1	<1	<1	<1	<1	<1
.10	4	2-62	4-0	4-0	4-0	4-0	2-47	4-0	4-0	4-0	4-0	2-4	4-0	4-0	4-0	4-0	<1	<1	<1	<1	<1	<1
.09	4.8	2-8.7	4-5.4	4.8-0	4.8-0	4.8-0	2-6	4-4.5	4.8-0	4.8-0	4.8-0	2-4.9	4-4.9	4.8-0	4.8-0	4.8-0	<1	<1	<1	<1	<1	<1
.08	6.0	2-12.8	4-7.6	6.0-0	6-0	6-0	2-7.8	4-6.3	6-0	6-0	6-0	2-6.2	4-6	6-0	6-0	6-0	1	1-0	1-0	1-0	1-0	<1
.07	7.4	2-19	4-111	7-7.6	7.4-0	7.4-0	2-10.5	4-8.5	7-7.5	7.4-0	7.4-0	2-8.1	4-7.7	7-7.5	7.4-0	7.4-0	1.3	1.3-0	1.3-0	1.3-0	1.3-0	<1
.06	9.5	2-28	4-17.2	7-11.4	9.5-0	9.5-0	2-14.2	4-11.7	7-10.2	9.5-0	9.5-0	2-11	4-10.2	7-9.6	9.5-0	9.5-0	1.8	1.8-0	1.8-0	1.8-0	1.8-0	<1
.055	11	2-32.5	4-22	7-14.5	11-0	11-0	2-17	4-13.8	7-12.2	11-0	11-0	2-12.7	4-12	7-11.2	1-0	11-0	2.2	2-2.3	2.2-0	2.2-0	2.2-0	<1
.050	13		4-28	7-18.5	13-0	13-0	2-20	4-16.5	7-14.7	13-0	13-0	2-15	4-14	7-19	14-12.5	21-12.5	2.69	2-2.8	2.69-0	2.69-0	2.69-0	<1
.045	15.3		4-35	7-24	14-15.4	15.3-0	2-24.5	4-20	7-17.8	14-15	15.3-0	2-17.7	4-17	7-15.7	14-15	21-15	3.2	2-3.6	3.2-0	3.2-0	3.2-0	<1
.040	18			7-32	14-20	18-0	2-30	4-25	7-22	14-18.7	18-0	2-21.3	4-20	7-19	14-18	21-18	4	2-4.8	4-0	4-0	4-0	1.07
.035	22.5			7-43.5	14-27	21-22	2-37	4-32	7-28	14-23.5	21-21.5	2-26	4-25	7-23.5	14-22.5	21-22.5	5.2	2-6.7	4-5.5	5.2-0	5.2-0	1.4
.030	27.5			7-58	14-37.5	21-31.5	2-40	4-40	7-36	14-31	21-28	2-33	4-31	7-29.5	14-28.5	21-28.5	6.9	2-9.5	4-7.6	6.9-0	6.9-0	2
.025	35				14-54	21-46		4-53	7-48	14-41	21-37	2-43	4-40	7-38	14-37	21-37	9.5	2-14	4-113	7-10	9.5-0	2.85
.020	47.5				14-80	21-70			7-66	14-58	21-53	2-54	4-55	7-52	14-50	21-50	13.5	2-21	4-17.5	7-15.8	13.5-0	4.4
.015	68					21-102				14-87	21-80	2-85	4-80	7-76	14-79	21-79	21	2-35	4-30	7-26	14-29	7.5
.010	109										21-140		4-133	7-125	14-122	21-122	37		4-56	7-50	14-45	15
.009	125										21-163			7-143	14-140	21-140	43			7-58	14-52	18
.008	140										21-190			7-165	14-160	21-160	50			7-68	14-61	21.3
.007	165														14-190	21-190	60				14-73	26
.006	195																73				14-92	32
.0065																	81				14-107	36
.0050																	91				14-118	41
.0045																	105					46
.0040																	118					54
.0035																	138					63
.0030																	163					75
.0025																						
.0020																						

Note:

1. Stay times given in days after detonation. First number is stay time in primary shelter, second number is stay time in secondary shelter.
2. Areas having no values have no solution.

All stay-times are given in "days after detonation." Interpolation can be done directly from the tables or by referring to the previous charts.

Other charts have been prepared as an aid to preattack planning. Figure 10 indicates, for any given reference intensity and permissible dose, the minimum primary shelter protection factor needed. This is based on the relationship indicated in Figure 1:

$$\frac{E'}{R_1} = \frac{2.67}{Pf}$$

$$\text{or} \quad Pf = \frac{2.67 \times R_1}{E'}$$

B. Shelter Specifications.

The information presented in this study provides a basis for a partial evaluation* of certain shelter specifications. Of particular interest are the protection factor and design stay-time.

The minimum protection factor recommended for family shelters (ref.8) is 100. If the acceptable maximum "survival" dose is 200r (ERD), the maximum "acceptable" reference intensity is about 7300 roentgens per hour (from Figure 10). That is, if the reference radiation intensity is greater than 7300 r/hr,** doses greater than 200r will occur.

The design stay-time in fallout shelters is generally assumed to be 14 days. As indicated previously, shelter stay-time is a function of the primary shelter protection factor, the radiation intensity level, the permissible dose, and the equivalent protection factor during the secondary

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* A more complete evaluation should be made on the basis of the probability of certain population groups receiving various fallout radiation doses. This determination is beyond the scope of this project.

** If the fallout arrives earlier than one hour, somewhat lower reference radiation intensities will also cause higher doses.

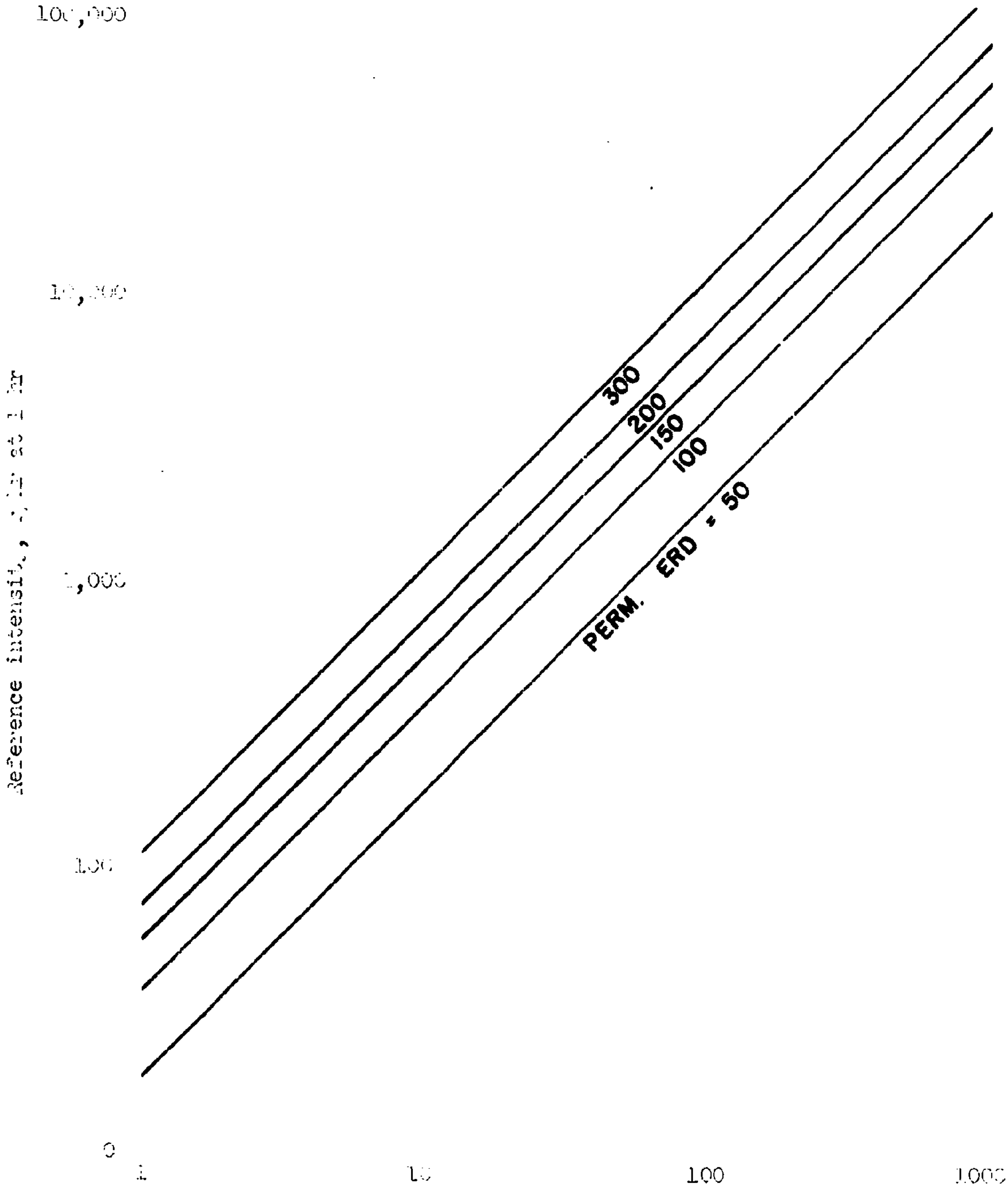

Figure 10

Maximum reference radiation intensity that permits controlling dosage to permissible level in various shelters.

shelter period. The relationships between these parameters for a constant 14-day stay-time value have been plotted on Figure 11. As an example, given a permissible dose (ERD) of 200r, a reference intensity of 6000 r/hr and a primary shelter protection factor of 100, the secondary protection factor will have to be 9.5 or higher to keep the stay-time to 14 days or less. If the primary protection factor is 1000, the secondary protection factor can be about 5.5. For a reference intensity of 7500 r/hr, the secondary protection factor must be 7 or higher to limit the stay-time to 14 days.

C. Requirements for Intermediate Shelters.

One important operational question is "How soon can persons return to their normal residence?" In the least complex situation, persons would stay in the primary shelter 24 hours a day until such time as the transfer to their normal residence could be made. The equivalent protection factors in the final period can be assumed to be about 2, considering the protection factor of the ordinary residence, the effect of weathering, etc. The stay-times for various shelters and the range of anticipated fallout radiation intensities are given in the upper section of Table 3. The numbers in parentheses are the times the peak occurs. As can be seen, at about 1000 r/hr the shelter stay-times are about 2 weeks. The dose peak occurs at about 7 weeks. At 3000 r/hr, the stay-times have become about 2 months, with dose peaks at about 4 months. If the final protection factor can be increased to 5, the lower portion of Table 3 indicates that the stay-times become somewhat more practical to achieve.

Another method of reducing shelter stay-time is the use of secondary shelters. This will be most feasible in areas where the blast effects have been minor, for it requires the use of areas in which an equivalent protection

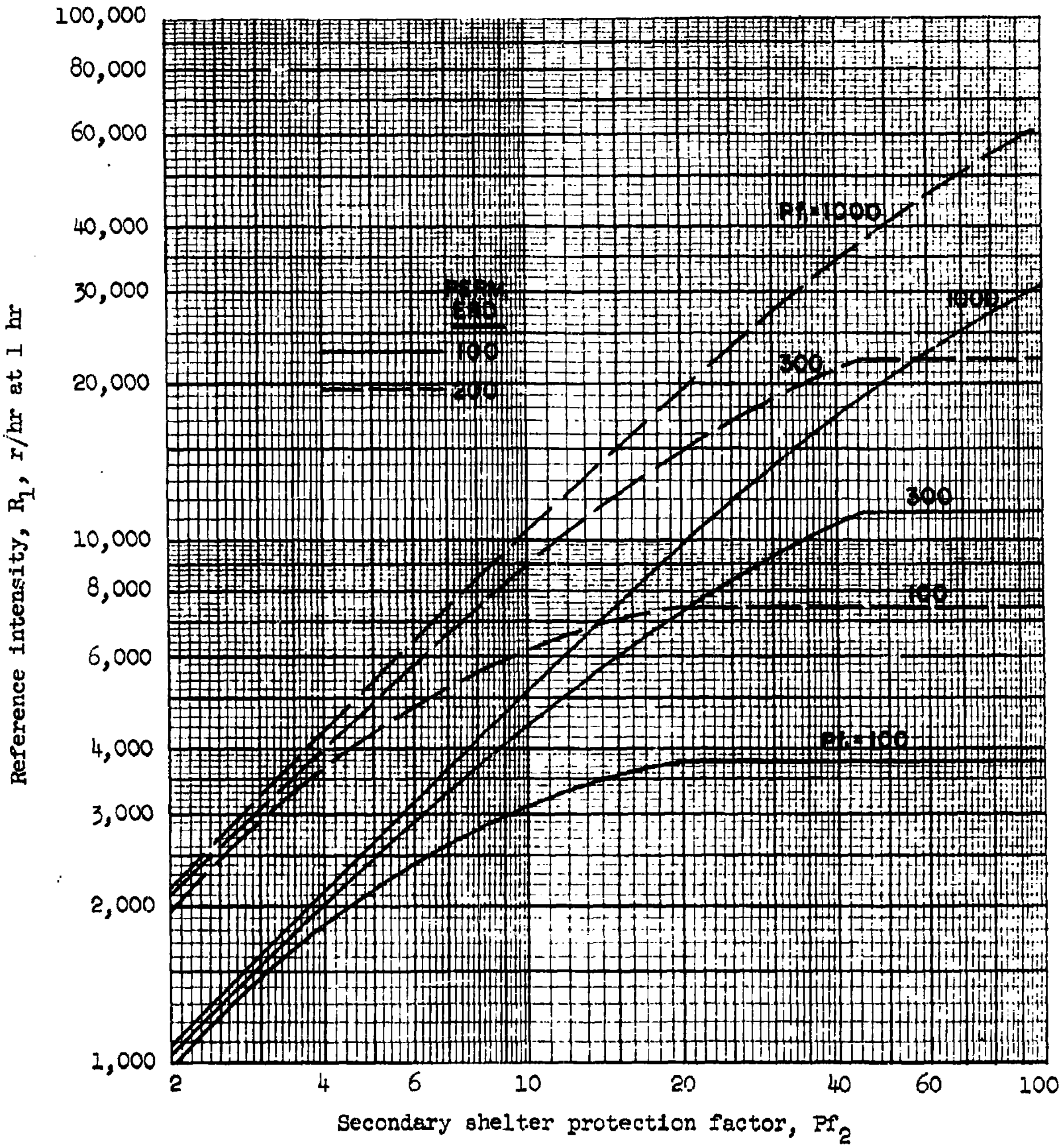

Figure 11

Fallout concentrations (reference dose rates) corresponding to 14 day stay-times in primary shelters for permissible ERD = 100 and 200 and for various secondary shelter protection.

Table 3

Required stay-time, days after detonation, in primary shelter to limit dose to 100r (ERD)

Primary shelter protection factor	Reference intensity, r/hr 300 r/hr	1000 r/hr	3000 r/hr	10,000 r/hr
	Final period protection factor = 2			
10	6 (17)*	D.E.**	D.E.	D.E.
30	2 (17)	23 (48)	D.E.	D.E.
100	1.6 (17)	14.5 (47)	68 (128)	D.E.
300	1.5 (17)	13 (47)	58 (125)	> 200 (>400)
1000	1.35 (17)	12 (46)	57 (120)	> 200 (~360)
	Final period protection factor = 5			
10	1 (8)	D.E.	D.E.	D.E.
30	< 1	10.5 (22)	D.E.	D.E.
100	< 1	3.5 (22)	26 (56)	D.E.
300	< 1	2.8 (22)	18 (56)	95 (170)
1000	< 1	2.5 (21)	17 (52)	85 (155)

* Numbers in ( ) indicate day that peak dose occurs.

** D.E. indicates permissible dose exceeded in primary shelter.

factor of 10 or 20 can be achieved. Many large buildings fall into this category. In other cases, decontamination can be used to improve the protection to the desired level. Table 4, abstracted from Table 1, indicates the primary and secondary shelter stay-times for 100 protection factor primary shelters in the critical reference radiation intensity range of 1000 to 3000 r/hr. Although the over-all shelter stay-time may be increased, the primary shelter stay-time can be shortened considerably. For instance, at 2000 r/hr reference intensity, the primary shelter stay-time is 44 days for a final protection factor of 2. If a secondary shelter having an equivalent protection factor of 10 is used, the stay-time in the primary shelter can be reduced to 7 days. The secondary shelter would have a stay-time of 54 days after detonation (or a net stay-time of 47 days). If the secondary shelter protection is 20 rather than 10, a shorter stay-time in each shelter phase can be achieved. A simultaneous improvement in the final protection considerably decreases the secondary shelter stay-time.

The requirement to reduce the primary shelter stay-time to a minimum has three principal objectives:

a. to increase the time (i.e., effort) available for productive effort in locations outside the primary shelter,

b. to permit the design specifications for the primary shelter to be made less restrictive, and

c. to minimize the period that persons must remain in the crowded environment that is basically unhealthy, mentally and physically.

Consequently, the relative worth of various countermeasures can be judged on the basis of stay-times in the primary shelter. The value of one measure with respect to another can be measured by the "stay-time saved." An example

Table 4

Stay-times, days after detonation,
associated with the use of secondary shelters.
(Permissible dose = 100r)

Primary shelter protection factor	Second period prot. factor	Final period prot. factor	1000 r/hr (E'/R_1 = .1)	2000 r/hr (E'/R_1 = .05)	3000 r/hr (E'/R_1 = .035)
100	2	2	15-15	44-44	69-69
			2-23*	D.E.**	D.E.
			4-20	D.E.	D.E.
100	10	2	7-17	7-54	D.E.
			14-15	14-49	14-81
			2-18	2-54	D.E.
			4-17	4-47	D.E.
100	20	2	7-16	7-46	7-70
			14-15	14-44	14-70
			2-10	D.E.	D.E.
			4-6	D.E.	D.E.
100	10	4	5-0	7-31	D.E.
			5-0	14-21	14-50
			2-6½	2-28	D.E.
			4-5½	4-24	D.E.
100	20	4	5-0	7-21	7-42
			5-0	14-19	14-36

* First number: stay-time in primary shelter; second number: stay-time in secondary shelter period; both values in days after detonation.

** D.E. indicates permissible dose is exceeded for primary shelter stay-times shown in the 1000 r/hr column.

of this is given in Table 5 for a $Pf_1 = 100$, a permissible dose of 100r, and a variety of reference intensities. The reference situation is $Pf_1 = 100$ and $Pf_2 = 2$.

The advantage of Pf_2 of 4 over 2 is obvious. The advantage of Pf_2 of 10 over 4 is apparent except at intensities less than 1000 r/hr. However, it appears that there is little advantage of having secondary protection factors greater than 10, as the decrease in stay-time proportionally is relatively small. Table 6 also gives the reduction in shelter stay-time for similar conditions except that the primary shelter protection factor is 1000. The conclusions drawn for $Pf_1 = 100$ apply to Table 6 also.

The time saved by three-stage operational situations is more difficult to determine precisely because primary shelter stay-times have been computed for 2, 4, 7 and 14 days only. However, using the available data, the time saved by introducing secondary shelters with a protection factor of 10 and 20 into a situation of $Pf_1 = 100$ and a final protection factor of 2 is given in Table 7. As expected and previously indicated, the use of secondary shelters greatly reduces stay-time. However, the advantage of Pf_2 of 20 over 10 is not great and only apparent above about 1300 r/hr. Similar conclusions can be drawn when $Pf_1 = 1000$.

Table 5

Reduction in primary shelter stay-times, days, by the improvement in the final period protection factor when $Pf_1 = 100$.

E'/R_1	R_1 *	Saving, days, when instead of 2, Pf_2 is: 4	10	20	50
.3	333	1	1	1	1
.2	500	3.5	3.6	3.6	3.6
.1	1000	9.8	14	14	14
.08	1250	14	20	21	21
.06	1670	17	24	26	26
.05	2000	26	38	42	43
.04	2500	32	48	54	57
.03	3300	41	62	70	76
.025	4000	DE	DE	DE	DE

Table 6

Reduction in primary shelter stay-times, days, by the improvement in the final period protection factor when $Pf_1 = 1000$.

E'/R_1	R_1 *	Saving, days, when instead of 2, Pf_2 is: 4	10	20	50
.3	333	.65	.65	.65	.65
.2	500	2.7	2.7	2.7	2.7
.1	1000	8	11	11	11
.08	1250	11	16	16	16
.06	1670	14	20	20	20
.05	2000	21	31	33	33
.04	2500	27	41	44	44
.03	3300	38	58	63	64
.02	5000	48	91	100	104

* Based on permissible dose of 100r.

Table 7

Reduction in primary shelter stay-time, days after detonation, achieved by the use of secondary shelter.*

		$Pf_1 = 100$		$Pf_1 = 1000$		
		Pf_2**:		Pf_2**:		
E'/R_1	R_1***	10	20	10	20	50
.3	333	< 1	< 1	< 1	< 1	< 1
.2	500	2.6	2.6	1.7		2.7
.1	1000	13	13	10		11
.08	1250	20	20	15		16
.06	1670	29	31	24	24	25
.05	2000	37	42	30	32	34
.04	2500	44	54	38	43	44
.03	3330	ND	66	58	63	64
.02	5000	DE	DE	91	98	104

ND indicates not determined.

DE indicates dose exceeded.

* Reference condition: Pf_1 = 100 or 1000, final protection factor = 2.

** Pf_3 = 2.

*** Based on permissible dose of 100r.

VI. LIMITATIONS TO INVESTIGATION

A basic approach for planning postattack operations has been developed. However, in order to develop more useful and valid planning tools, additional investigations are necessary. Most important are sensitivity analyses for the various input parameters. The effect of different fallout radiation characteristics on the dose and stay-time relationships should be determined. For example, a one-hour effective arrival time was used in conjunction with the reference intensity. Obviously, other arrival times should be checked for their influence on the dose and to provide a basis for determining a method for incorporating this variable in the computation. The decay rate, also, should be varied. The computations were based on the use of a constant decay exponent of 1.23 throughout an entire year. Actual decay rate exponents are apt to vary considerably at early times from detonation to detonation. In addition, the decay rate is expected to change at about 6 months. Consequently, it is desirable to investigate the effect of various decay exponents, say 1.1, 1.2, 1.3,* as well as the effect of more realistic decay curves such as those by Moreland (ref.6), Miller (ref.9), and Kleinecke and Doughty (ref. 10). Fortunately, the computer program is set up in such a way that duplicate computations can be made for different radiation data with very little difficulty.

The sensitivity of the results to variations in the constants used in the equivalent residual dose equation is desirable. Although some comparisons have been made (refs.11,12), they have not been made for complex operational situations.

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* The use of an exponent that changes periodically can also be evaluated.

VII. SUMMARY OF CONCLUSIONS

Computations have been made of the equivalent residual dose anticipated in various standardized radiological situations. The information has been presented in a preliminary form that is useful for preattack planning of generalized postattack operations. Although the basic computational program can accommodate daily changes in shelter protection factor, the preliminary charts are set up on the basis of a maximum of three protection factor situations during the first year.

The basic dose-stay-time data has been used for a limited number of operational evaluations. One of the more important results of these studies is the indication of the need for secondary shelters that have a protection factor of about 10. Such shelters, serving as temporary living and working areas, will permit a significant reduction in primary shelter stay-time.

VIII. RECOMMENDATIONS

The study described in this report provides an approach to operational planning that utilizes a dose-concept based on biological recovery. The continued development of this approach is highly desirable. The initial steps taken herein to present the information in a manner useful to the planner must be considered preliminary and subject to additional consideration. As previously indicated, sensitivity (or error) analyses are necessary, and means of incorporating consideration of sensitive parameters must be developed.

The planning approach presented herein is primarily useful for preattack planning. More specifically, it can be considered as applying to persons who do not perform emergency operations such as rescue, reconnaissance, decontamination, etc. Since these are special exposure cases, some variation of the basic approach is needed to provide for dose computations for this type of worker. Actually, the computer program can handle such problems without difficulty, but the simplification of the computation to manual methods is apt to be very complex.

The postattack planning and exposure control problems are sufficiently different from the preattack planning to require separate consideration. For instance, the planner will have available measured values of the first day dose, decay rate, protection factors, etc. He will be faced first with comparing preattack plans with the post-situation. In addition, he must consider actual exposures (as measured by dosimeters) as well as predicted exposures. Consequently, he may need somewhat different dose-stay-time computational and planning methods. An inexpensive, portable analog computer may be a solution to this problem. The performance specifications for such a unit have been prepared (ref.13). It is anticipated that it would be useful for both preattack and postattack planning. The development of this device should be continued.

The development of the use of the equivalent residual dose concept in planning will permit re-evaluation of many operational considerations. The performance specifications for primary shelters can be evaluated in terms of the availability of secondary shelters. The need for and specifications for secondary shelters can be determined. This latter consideration leads to the development of specifications for decontamination and reclamation systems. In addition, the dose expended in such operations must be evaluated in order to determine the operational regimen of decontamination personnel. The equivalent residual dose concept permits this to be done on a more realistic basis than has been possible.

Appendix A

EQUIVALENT PROTECTION FACTOR COMPUTATION

The equivalent protection factor is the "average" protection factor for a day's activity. When it is divided into the daily (exposed-location) dose increment, r_i, the quotient is the dose to those persons participating in the activity. This approach simplifies the over-all computational problems by permitting the dose increment to be one day.* Generally, this introduces no serious inaccuracies in computations of operational situations involving radiation exposure during a period of several days.

Obviously, a wide variety of protection factors are normally encountered in daily activities. In the postattack period, activity will be limited. Initially, personnel will be restricted to a single shelter. In the reconnaissance period, some personnel will leave the shelter for a few hours per day. As recovery begins, personnel will be away for extended periods, perhaps returning to the shelter only to sleep. As other work assignments become available and persons move to secondary shelters, the situation becomes more complex. The basic equation for determining the equivalent protection factor in such a situation is:

$$Pf = \frac{1}{f_1/P_1 + f_2/P_2 + \dots f_n/P_n}$$

where: P_i = the protection factor of the i^{th} shelter

f_i = the fraction of the day spent in the i^{th} shelter

(note: $\Sigma f_i = 1.0$).

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* Planning of operations during the first day or so may require a more detailed time increment consideration. Such planning is considered beyond the scope of this study.

In order to facilitate estimations of the equivalent protection factor, Figures A-1, A-2 and A-3 have been prepared for several simplified systems. The specific equation used was:

$$Pf = \frac{1}{f_s/P_s + f_o/P_o + f_w/P_w}$$

where P_s = protection factor of the sleeping and living area,

P_o = protection factor during transit to and from working area,

P_w = protection factor in working area,

f_s, f_o, f_w = corresponding fractions of day spent in each activity.

Specifically, Figure A-1 indicates Pf for a wide variety of shelter area and working area protection factors when 8 hours per day are spent in the shelter and 16 hours per day in the working area. Travel time is assumed negligible. Figure A-2 is similar to A-1 except that one hour per day is considered travel time at a protection factor of two, the time being deducted from the working time. Figure A-3 is similar to A-2 except that 11 hours are spent in the shelter, one hour in transit and 12 hours working.

Other precalculations of the equivalent protection factors are included in references 2 and 7.

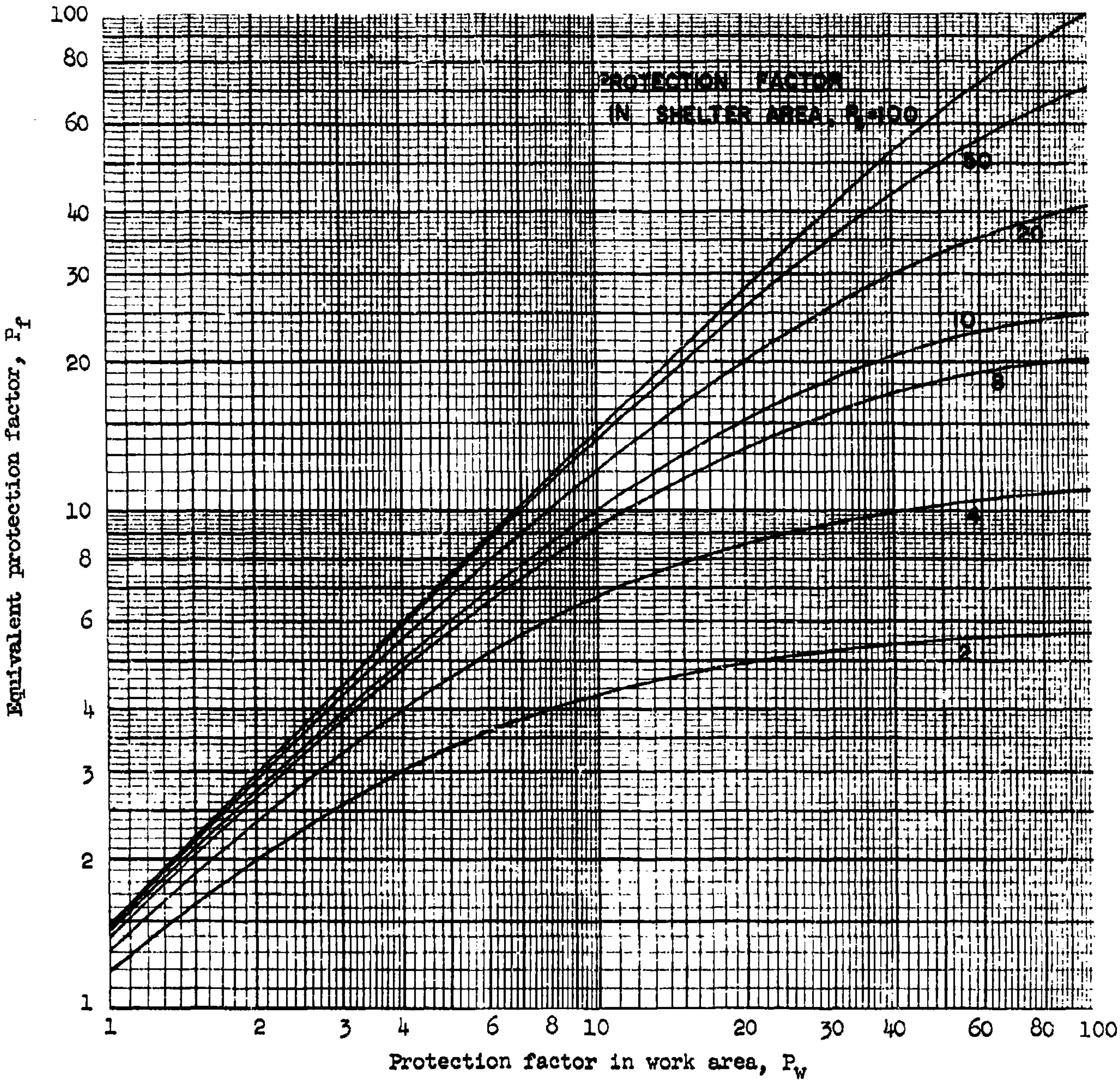

Figure A-1

Equivalent protection factors for various combinations of protective areas and occupancy times.

Note: P_s = 2 to 100 $\quad$ P_o = 1 $\quad$ P_w = 1 to 100

f_s = 8/24 $\quad$ f_o = 0 $\quad$ f_w = 16/24

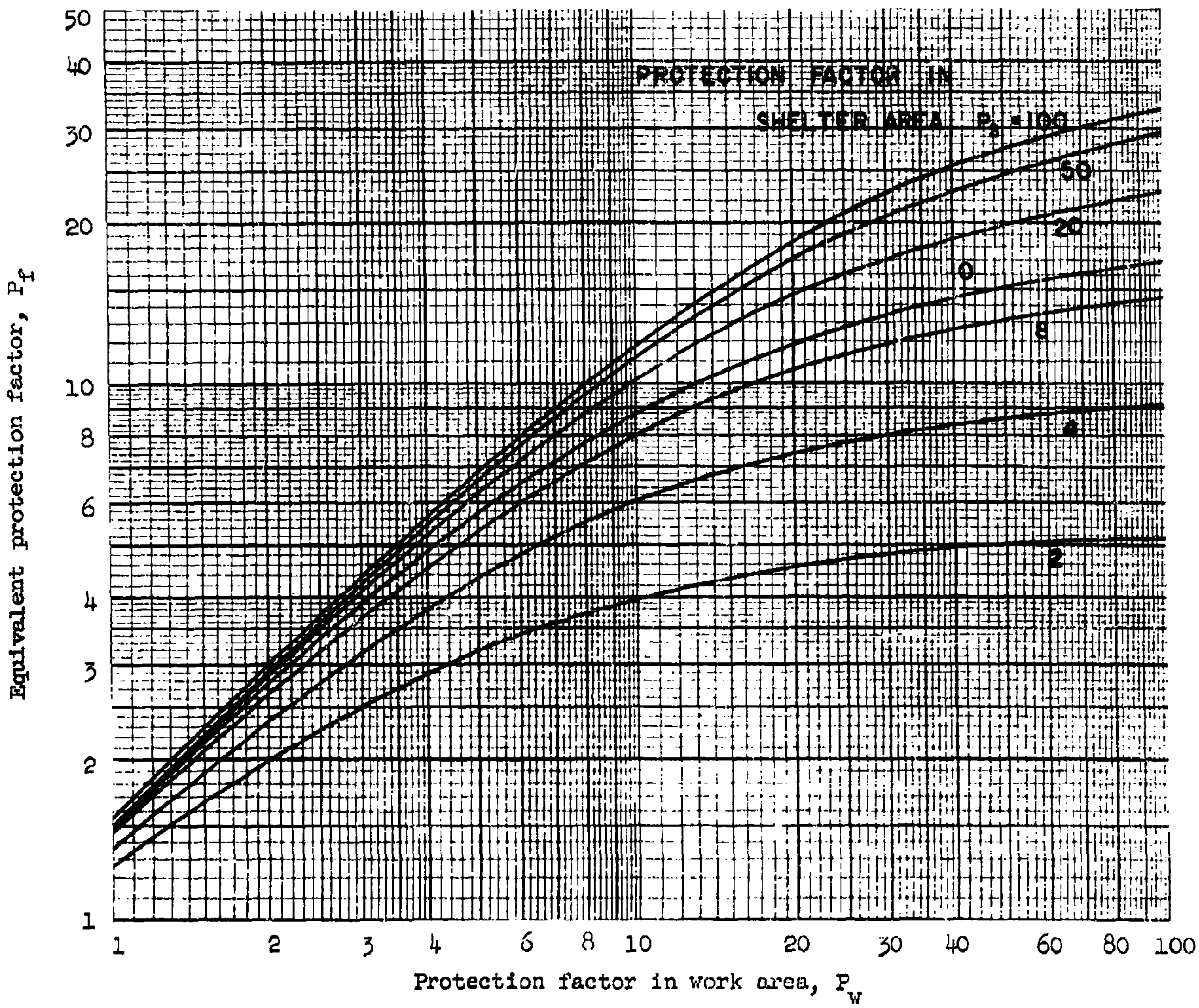

Figure A-2

Equivalent protection factors for various combinations of protective areas and occupancy times.

Note: $P_s = 2$ to 100 $\quad P_o = 2$ $\quad P_w = 1$ to 100

$f_s = 8/24$ $\quad f_o = 1/24$ $\quad f_w = 15/24$

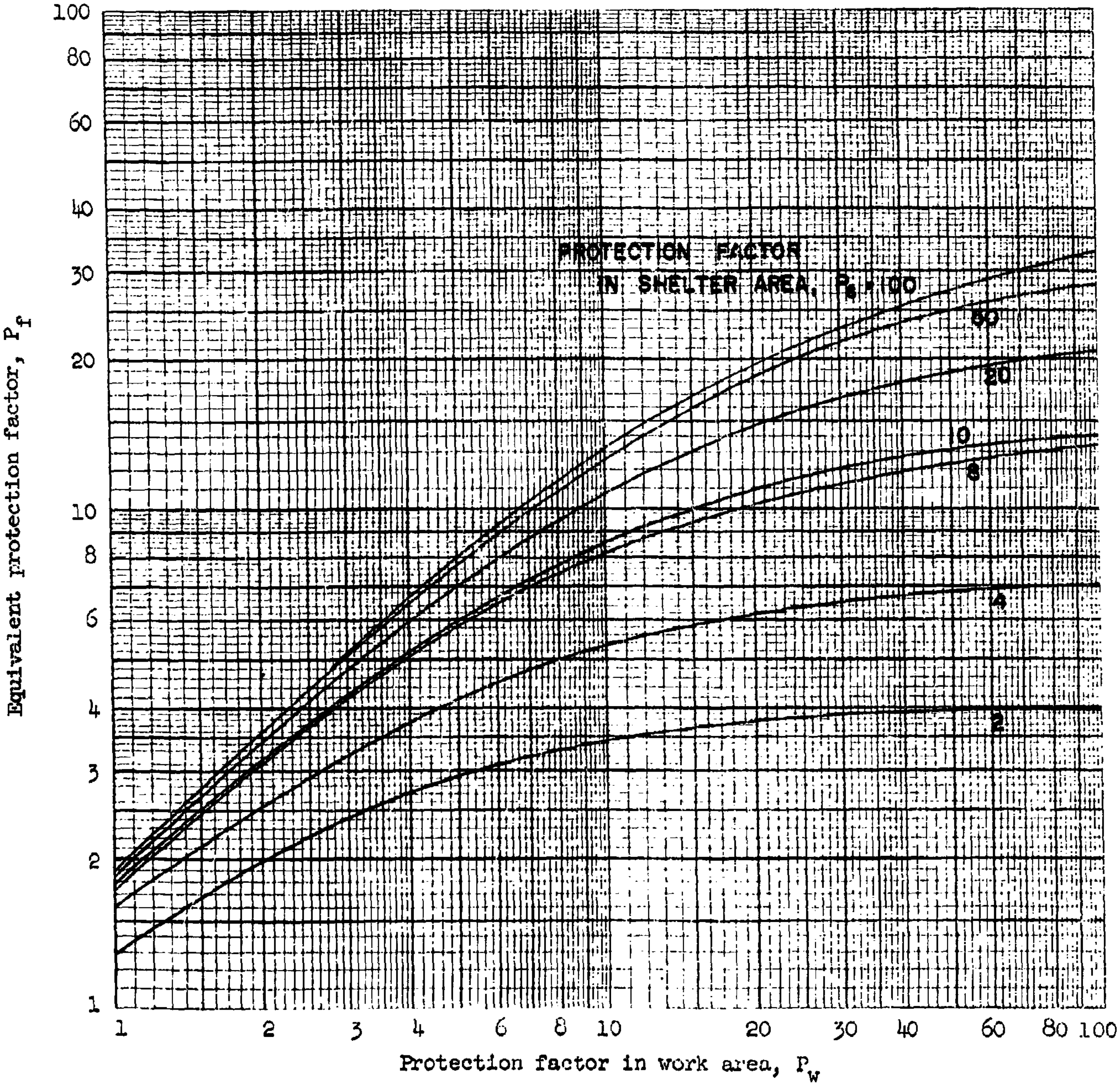

Figure A-3

Equivalent protection factors for various combinations of protective areas and occupancy times.

Note: P_s = 2 to 100 P_o = 2 P_w = 1 to 100

f_s = 11/24 f_o = 1/24 f_w = 12/24

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